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# Drinking Water Pilot Study: Summary

NATO Committee on the Challenges of Modern
Society, Brussels (Belgium)

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The Drinking Water Pilot Study was initiated by the U.S. EPA in order to address a broad spectrum of drinking water quality and health related issues. Six subject areas have been studied by a number of groups representing individuals from eleven NATO countries and three non-alliance countries with technical participation from many others. The topic areas include Analytical Chemistry and Data Handling (Area I), Advanced Treatment Technology (Area II), Microbiology (Area III), Health Effects (Area IV), Reuse of Water Resources (Area V), and Ground Water Protection (Area VI).

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# Committee on the Challenges of Modern Society (NATO/CCMS)

## Drinking Water Pilot Study Summary

NATO/CCMS Drinking Water Pilot Project Series

CCMS 130

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# COMMITTEE ON THE CHALLENGES OF MODERN SOCIETY

# (NATO/CCMS)

# DRINKING WATER PILOT STUDY

## SUMMARY

Edited by:
Ervin Bellack and Joseph A. Cotruvo,
U.S. Environmental Protection Agency

NATO/CCMS Drinking Water Pilot Project Series
Joseph A. Cotruvo, Chairman

CCMS # 130

# FOREWORD

Many of the industrialized Nations face problems such as population, energy, and protection of the environment. In order to optimize the use of the scientific and technical expertise from different countries, the Committee on the Challenges of Modern Society (CCMS) was created between the Allied Nations of the North Atlantic Treaty Organization (NATO). This international society of scientists strengthens ties among the members of the North Atlantic Alliance and permits NATO to fill a broader social role with non-member countries. CCMS has been responding to the increasingly complex, technological problems facing modern society.

The Drinking Water Pilot Study was initiated by the U.S. Environmental Protection Agency in order to address a broad spectrum of drinking water quality and health related issues. Six subject areas have been studied by a number of groups representing individuals from eleven NATO countries and three non-alliance countries with technical participation from many others. The topic areas include Analytical Chemistry and Data Handling (Area I), Advance Treatment Technology (Area II), Microbiology (Area III), Health Effects (Area IV), Reuse of Water Resources (Area V) and Ground Water Protection (Area VI).

I. Analytical Chemistry - Pilot country, United Kingdom; Chairman, Lawrence R. Pittwell, British Department of the Environment.

This report consists of the present practices as well as the research being conducted by the participating nations. This includes the sampling frequencies and methods, the national laws and regulations, the analytical methods used and the present analytical and related research in progress. The report is intended to serve as a data base for others involved in similar work, or who have common problems, and to be a basis for collaboration to avoid unnecessary duplication of research and improve the quality of drinking water throughout the world.

II. Advanced Treatment Technology - Pilot country, Federal Republic of Germany; Chairman, Heinrich Sontheimer, University of Karlsruhe.

Two international symposia, entitled, "Oxidation Techniques in Drinking Water Treatment" at Karlsruhe, Federal Republic of Germany and "Adsorption Techniques in Drinking Water Treatment" at Reston, Virginia, form the basis for the report. Herein are two comprehensive surveys of the practical application of adsorption and oxidation techniques for removing organic chemicals from drinking water. Both of these symposia represented the most up-to-date technical assessments of the state-of-the-art for those technologies and provide data from working installations in a number of countries.

III. Microbiology - Pilot country, United States; Chairman, Dean O. Cliver; University of Wisconsin, Food Research Institute.

The intent of the microbiology group was to incorporate into the project a survey of virtually all aspects of drinking water microbiology that have practical significance. Their report includes sections on raw water microbiology, waterborne pathogens, indicator systems, testing and standards, treatment processes, distribution systems and technological aspects of potable water microbiology.

IV. Health Effects - Pilot country, United States; Chairman, Joseph Borzelleca, Medical College of Virginia.

The Area IV report includes information on toxicological issues, carcinogenicity and mutagenicity, chemical constituents physical constituents, and epidemiological considerations associated with drinking water. The proceedings of a comprehensive symposium on Drinking Water and Cardiovascular Disease is also included. This latter area is the most up-to-date analysis of the controversial and potentially significant role of drinking water quality factors on cardiovascular disease risk factors in consuming populations.

V. Reuse of Water Resources - Pilot country, United Kingdom; Chairman, Albert Goodman, Department of the Environment.

A summary of the reuse laws and practices in the participating countries forms the basis for the report. Also included is a symposium entitled, "Protocol Development: Criteria and Standards for Potable Reuse and Feasible Alternatives". This examined the technical status of methods for producing high quality water from poor quality sources, and techniques for determining the safety of consuming recycled water, as well as social and economic aspects of the decision.

VI. Ground Water Protection - Pilot country, Federal Republic of Germany; Chairman, Horst Kussmaul, Institut fur Wasser, Soden-und Lufthygiene.

This is a report on the quality and quantity of ground water resources, with emphasis on recharge and production from contamination.

This volume is a summary of the efforts in all six areas of the NATO/CCMS Drinking Water Project.

This report is a tribute to the efforts for all the participants involved. It is hoped that the ties established and the good spirit of international cooperation that has prevailed through the completion of this report will continue in the development of future related projects.

Joseph A. Cotruvo, U.S. EPA
Chairman, Drinking Water Pilot Project
NATO/CCMS

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# CHAPTER I

## EXECUTIVE SUMMARY

The NATO/CCMS Drinking Water Pilot Study was initiated in the hope of achieving a better understanding of the drinking water problems that are shared by all countries and to consider possible solutions to those problems. The aim of the pilot study is to produce a comprehensive report on state-of-the-art matters relating to drinking water in the participating nations, including evaluations of existing technology and practice from the points of view of effectiveness, public health protection, practicality, costs, general availability and association by-product hazards.

The study has been organized by the United States of America with the assistance of the copilots the United Kingdom and the Federal Republic of Germany, into six individual topics, which were assigned as follows:

1. Analytical Chemistry and Data Handling - Lawrence R. Pitwell, Department of the Environment, United Kingdom

2. Advanced Treatment Technology - Dr. Heinrich Sontheimer, Engler-Bunte-Institut der Universitat Karlsruhe, Federal Republic of Germany

3. Microbiology - Professor Dean O. Cliver, Food Research Institute, Department of Bacteriology, University of Wisconsin, United States

4. Health Effects - Professor Joseph F. Borzelleca, Division of Toxicology, Medical College of Virginia, United States

5. Reuse of Water Resources - Albert Goodman, Department of the Environment, United Kingdom

6. Ground Water Considerations - Dr. Horst Kussmaul, Institut fur Wasser-, Boden - und Lufthygiene des Bundesgesundheitsamtes, Federal Republic of Germany

Dr. Joseph A. Cotruvo of the Office of Drinking Water, U.S. Environmental Protection Agency, was overall chairman of the pilot study on behalf of the pilot country, the United States of America.

Each of these study groups has prepared a final report and arrived at a number of conclusions and recommendations. These represent the thoughts of the individual participants and do not necessarily represent national policies. The recommendations include both suggestions for actions to be taken in specific areas and suggestions for further study. Some of the significant features of the individual study group reports are summarized in the following sections. Full summary reports and recommendations are in later chapters and the full reports of each group are published separately in this series.

The CCMS mechanism has been a most effective mechanism for international contact and information exchange in the rapidly developing area of the science and technology of drinking water. Since it operates in the absence of a regulatory context, it has provided direct access to the latest concepts in an unrestricted forum that has encouraged free interchange and rapid acceptance. Since the field is developing rapidly, the program should continue in specific areas with a follow-up mechanism for the application of findings.

## Area I, Analytical Chemistry and Data Handling,

Laurence R. Pittwell, Chairman

The ultimate aim of chemical analysis in the drinking water industry is to provide data which are useful in the safeguarding of the quality of water intended for human consumption. There is no need or desire to analyze water for analysis sake, nor is there a need or desire to identify or quantify every possible constituent in drinking water. The parameters to be measured, the frequency or monitoring, the analytical and sampling methods used and the national analytical quality assurance procedure of each country are determined by specific needs. The needs in turn are determined by the characteristics of the water being studied.

The Analytical Chemistry and Data Handling study group wrote their report on the basis of a survey of present practice and problems in interested nations. Some problems, and thus some conclusions and recommendations, are common to virtually all countries. These include the need for monitoring in accordance with specific requirements, the need for the establishment of data handling requirements, and the need for adaptation of analytical chemistry, in all of its aspects, to future developments in industry, treatment processes and public health.

In the area of monitoring, the study concluded that, if public health is to be safeguarded, the minimum requirement for even the purest water is a periodic check of the quality of the source water as well as the water at the consumer's tap. The monitoring should take into account the risks likely to be encountered by the consumer and where practicable, source monitoring and should be done in such a way that in the event that contamination is discovered there is ample time for remedial action to be taken before the water is processed. Process control monitoring is needed to ensure that the quality of water leaving the treatment plant is satisfactory, and distribution system monitoring is needed to assure that the quality of water reaching the consumer has not deteriorated en route.

The study group paid particular attention to the status of analytical methods used in drinking water analysis, and they recommended that only proven accurate standardized methods be used, methods must be suitable for use with the water analyzed and the situation in hand. Because it is often impossible or undesirable to choose one single method for a parameter which will suit all water types, which will suit every laboratory situation, or which will suit every budget, there should be a choice of methods of known performance for each parameter. Where the analysis for a particular parameter is time-consuming or costly, an appropriate rapid empirical test should be devised and used routinely. In fact, the study group felt that there is a need for quicker, cheaper methods for many parameters, as well as for continuous monitoring methods for some methods for distinguishing the form in which a chemical is present. For the hundreds of organic chemicals that have been identified in some waters, the study group recommended the development of rapid simple methods, but noted that there is little point in identifying increasing numbers of microtrace impurities unless there is an indication that a real hazard exists. The group also noted that little attention has been paid to the natural organic matter which constitutes the bulk of the total organic content of drinking water.

Since even use of a method of proven accuracy does not completely guarantee the validity of the result, the study group emphasized the need for adequate control of analytical quality both within and between laboratories. Other areas explored included sampling methods, storage and preservation of samples, training of laboratory techniques, reproducibility and reliability characteristics of analytical methods, testing of waters for additives from water-contact materials, record keeping and exchanges of information. The group considered mentioning certain parameters for which analytical methods are inadequate, but declined to do so on the basis of rapid changes in analytical research and analytical requirements. The group noted that their potential list changed several times while their report was being drafted. Their final recommendation was that information exchanges in the fields covered by their report should be arranged at intervals in the future.

Some of the key concepts arrived at by the analytical chemistry study group are:

- Process control analyses need to be adequate to ensure that the quality of water leaving the waterworks is satisfacory, and that, in addition, samples should be collected at representative points throughout the distribution system to assure that the water reaching the consumer is of the same quality.

- When the analysis for a specific hazardous substance is time-consuming or costly, an appropriate rapid empirical test should be devised and used routinely; but sufficient full determination should be made at regular intervals to assure the continued validity of the control analysis.

- There should be adequate control of analytical quality both within and between laboratories. It is realized that interlaboratory tests are very difficult to to organize in such a way that meaningful results are obtained, hence, such interlaboratory tests should be used sparingly but thoroughly.

Some of the major conclusions and recommendations of the analytical chemistry study group are:

- Monitoring must be adequate, the results must be obtained in time to be of use, and be of assured quality. In order to be assured of the quality of data generated, the laboratory must be certified as being capable of performing the analyses, there must be an effective system of quality control, and there must be a continuing program for quality assurance which includes interlaboratory testing and methods evaluation.

- Monitoring procedures should be tailored to the individual raw water and treatment process, be of a quality to reflect the probability of contamination existing, and consider the relative risks from the contaminants being monitored. The potential for contamination being introduced from components of the distribution system must be recognized, and sampling at the consumers' taps must be a part of the monitoring scheme.

- The ultimate aim of chemical analysis in the drinking water industry is to provide data to safeguard the quality of the water drunk, or used in cooking and cleaning, rather than the provision of a historic record of past events, even though such a record may have a place in the assessment of seasonal changes or gradual trends necessary to the setting of future operational policy.

- There is no point in identifying increasing numbers of microtrace impurities unless there is an indication that a real hazard exists, while quite large amounts of some other classes of substances remain unidentified. For example, although hundreds of organic chemicals have been identified in some waters at microgram or nanogram levels, very little is known about the humics, fulvics and lignins that may constitute 80% of the total organic carbon in water.

## Area II, Advanced Treatment Technology

Professor Heinrich Sontheimer, Chairman

During the past ten to fifteen years, water treatment technology has changed considerably. Many improvements have been made, such as the use of multi-layer filters for more efficient and economical filtration, and important changes have been introduced regarding new concepts of process design, especially in conjunction with more frequent use of technologies such as oxidation and adsorption. There are two important reasons for the incorporation of such methods in the treatment process. First, analytical methods have shown that many surface and ground water are being polluted with synthetic organic chemicals that cannot be removed effectively by standard treatment methods. Second, breakpoint chorination, while in many respects effective from both technical and economic viewpoints, has certain significant disadvantages. Through the reactions of free chlorine with organic constituents, chlorinated organic compounds such as chloroform and many other chemicals are formed. This can occur under conditions necessary for safe disinfection of the drinking water if precursor concentrations are high, and can potentially contribute health risks, especially if these contaminants have formed in higher concentrations.

Chlorine has been and will probably continue to be the most widely used oxidant and disinfectant for drinking water. Its use has been remarkable for controlling waterborne transmission of disease-producing organisms. The discovery of potentially hazardous chlorinated by-products has led to scrutiny of uncontrolled or excessive use of chlorine. Oxidants, such as ozone and chlorine dioxide, as well as technologies to reduce the amount of oxidant that is needed, have been widely used in many countries. It should be recognized that all oxidants produce chemical by-products, and that we have insufficient information at time to determine whether the by-products of the other oxidants are of more or less concern than the by-products of chlorine use.

The types, variety and quantity of contaminating chemicals found in surface and ground waters differ and the treatment would also differ. Surface water affected by industrial or municipal waste discharges may contain a variety and large number of synthetic organic chemicals, usually each at very low concentrations (fractions of parts per billion). The majority of organic substances are of natural origin (e.g., humic and fulvic substances) and these will react with oxidants such as chlorine or ozone to produce a variety of chemicals. On the other hand, when ground water becomes contaminated it is often by a few substances and often at higher concentrations than found in surface waters. The most frequently detected organic chemicals in ground water are the volatile halogenated solvents such as trichloroethylene and tetrachloroethylene. These are commercially produced in very high volumes, widely used in industry, and chemically and biologically stable.

The present study has concentrated on oxidation and adsorption technologies that deal with organic chemical contamination. A similar study on coagulation technology would definately be in order.

Even the most sophisticated analytical methods currently available cannot identify all contaminants in drinking water. Thus, water systems should emphasize source protection and comprehensive treatment to assure consistent finished water quality.

Member states should conduct monitoring surveys of ground waters to determine if they are being contaminated by waste disposal practices. This should include analyses of at least the volatile organic chemicals (halogenated and other). There should be regular monitoring of raw water, treatment processes, final water quality and distribution systems. In addition, there is a need for quality control and quality assurance mechanisms to insure the validity of the monitoring and analytical processes.

The Advanced Treatment Technology study group of the NATO/CCMS Drinking Water Pilot Study presented their report on the results of international studies concerning the state of the art of the application of oxidation and adsorpton techniques (including granular activated carbon) in the treatment of drinking water in the form of two conferences - the first held in Karlsruhe, Germany, in September 1978, and the second in Reston, Virginia, USA, April 30 - May 2, 1979. These conferences, sponsored, respectively by the Federal Republic of Germany and by the U.S. Environmental Protection Agency jointly with NATO/CCMS, did not attempt to prescribe general rules for the utilization of oxidative and adsorptive treatment processes, but rather were intended to draw attention to the potential benefits to be attained and to the problems remaining to be solved, as well as provide detailed information on the performance and costs of various technologies.

The major concepts evolving from the conferences included:

- Treatment of surface waters for drinking water purposes must include flocculation and filtration.
- In order to avoid possible disadvantages of breakpoint chlorination, additional treatment steps may be required to achieve a greater reduction in overall organics concentration.
- Pretreatment before flocculation, including the use of storage basins or ponds, prechlorination with dosages under the breakpoint, preozonation and riverbank filtration often enhances finished water quality.
- When breakpoint chlorination is omitted, an alternative process should be used to achieve reliable disinfection. The alternatives include ozonation, biological treatment particularly in conjunction with granular activated carbon filters, and disinfection with chlorine or chlorine dioxide at the end of the treatment process.

- While breakpoint chlorination is effective for ammonia removal, another method for nitrification may be necessary if chlorination cannot be used. Biological ammonia oxidation may be a viable alternative.

- Granular activated carbon filters have been used for many years for taste and odor removal, but there is still a widespread lack of knowledge concerning this treatment step, however, several facilities are successfully operating.

- Carbon filters can be used for (1) removal of specific organics such as chloro compounds and aromatic hydrocarbons, (2) reduction of total organic carbon and chlorine demand, (3) biological oxidation of ammonia, (4) taste and odor removal, and (5) dechlorination.

- Biological activity in carbon filters can increase time and throughput between carbon reactivations two to five times without sacrificing water quality, especially if preozonation is being used.

Other processes for organics removal discussed at the conferences included adsorption with synthetic resins, the removal of humics by microreticular anion exchange resins, aeration for removal of volatile contaminants, and membrane processes. The conclusion reached by the study group was that it is not possible to propose one preferred combination of treatment options that can replace the standard treatment configuration.

However, the oxidation and adsorption processes discussed offer many possibilities as part of a complete treatment requires that can be tailored to cope with each treatment problem that is encountered in the wide variety of water that are used as drinking water supplies.

## Area III, Microbiology,

Dean O. Cliver, Chairman

Potentially the most significant constraint upon the scope of the microbiology project was that it was to address the drinking water supply problems of industrialized nations. Significant features of drinking water supplies in industrialized nations are high volume usage, both for consumption and other applications, and the potential for microbiological contamination of source water because of water reuse.

The Microbiology study group incorporated into their project a survey of virtually all aspects of drinking water microbiology that have practical significance to the water microbiologist. Their report includes sections on (1) raw water microbiology, (2) water-borne pathogens, (3) indicator systems, (4) testing and standards, (5) treatment processes, (6) distribution systems, and (7) technological aspects of potable water microbiology. In addition to specific recommendations pertinent to each section, the following were among the major recommendations provided by the group:

- Every public water supply should begin with the highest quality raw water that is available in quantities sufficient to meet the community's needs. Efforts to protect and improve the quality of source waters are important; both waste discharges and non-point sources of pollution should be considered in attempts to prevent or alleviate contamination. Where possible, water to be used for irrigation, or for industrial purposes other than food, drug, or cosmetic manufacture, should usually be drawn from less pure sources than those from which the public supply derives.

- Disinfection is necessary, but not always sufficient, to ensure the safety of drinking water from virtually any source.

- Complete treatment of drinking water, including at least coagulation and sedimentation with sand filtration or alternatively dual filtration including effective slow sand filtration, followed in all cases by disinfection, is essential in all cases where source waters are unprotected and is highly desirable even with protected sources.

- Sound engineering practice is required to produce safe drinking water; microbiologic laboratory testing performed on a routine basis, according to standardized methods, and by properly trained and supervised staff, is an important basis for assessment of drinking water quality. Indicator systems for use in these tests may be selected for any one of the following purposes: (i) to signal fecal contamination; (ii) to detect any abnormal and probably undesirable conditions that may occur; or (iii) to warn of the probable presence of specific pathogens. Larger waterworks, at least, should develop microbiologic quality control procedures and baseline data for all stages of treatment from raw water through distribution. Prompt corrective action should be taken when norms are exceeded. At least one microbiology laboratory in each country should have the ability to detect waterborne pathogens, either for spot-checking or for investigating outbreaks, both from water samples and from clinical specimens. Results of tests for both indicators and pathogens should be shared on an international basis.

- In addition to the well-established research on waterborne bacterial pathogens, considerably more research is needed concerning viruses and protozoa transmissible by drinking water, in the areas of the dose-dependence of peroral infectivity and pathogenicity, the detection of these agents in water, and their removal or destruction by water treatment and disinfection processes.

- Materials of which water treatment and distribution facilities are constructed should be pretested for chemical and biological stability. Testing methods, as well as results, should be shared internationally as much as possible; however, it is also best to test materials, before use in a given system, with the very water with which they will, in fact, be in contact.

- Finished water in distribution, in both public and semipublic systems, should be sampled at representative locations and tested microbiologically with a frequency that depends on the size of the population served. Private water supplies should be tested at least annually. In all instances, the presence of coliforms, thermo-tolerant coliforms, or E. coli in a 100-ml sample should be treated as unacceptable, or at the very least, undesirable.

- To minimize aftergrowth or other technological problems and to provide a means of determining whether cross-contamination has occurred, water in a public supply distribution should wherever possible contain a measurable residual level of disinfectant (e.g., free chlorine at all points.

- Means are needed to control cross-connections, to ensure both that the consumer does not degrade publicly-supplied water to the detriment of his own health and that his use of the water does not cause contamination that threatens the health of others. Aspects of particular concern include water attachment devices that use water, and point-of-use treatment units attached to the consumer's tap.

## Area IV, Health Effects

Professor Joseph Borzelleca, Chairman

The committee addressed two major topics; the chemical and physical contaminants in drinking water. A list of 744 chemicals, their country of origin, concentrations, source and treatment was compiled.

The origin of these contaminants, natural, man-made or as the result of water treatment was discussed. Naturally occurring contaminants included organic and inorganic chemicals. The anthropogenic chemicals included atmospheric, industrial, agricultural, landfill, surface runoff and household chemicals. Contaminants formed as the result of water treatment included trihalomethane and chlorinated aromatic and non-aromatic compounds.

Contaminnats contributed from the distribution system included leachates from piping, polycyclic aromatic hydrocarbons and corrosion products. The committee identified the following substances as worthy of further study: halogenated methanes, polycyclic aromatic hydrocarbons, asbestos, chlorinated phenols and cations. An additional eleven chemical classes and one physical class were identified for further evaluation.

The committee concentrated on the question of whether drinking water contamination could result in adverse health effects of the chemical contaminants.

Various methods of disinfection are successfully used to control water-borne diseases due to biological contaminants in water (viruses, bacteria). Varying methods of chemical control add chemical contaminants to the drinking water. For example, chloroform and carbon tetrachloride have been found as contaminants in chlorine gas. Trihalomethanes may be formed by the interaction of chlorine with humic and/or fulvic acids. In addition, chemical contaminants may arise from natural, agricultural, industrial or distributional sources. Acute or chronic exposures to these chemicals could theoretically result in adverse health effects that are immediate or delayed, reversible or irreversible. Since these contaminants rarely occur singly, chemical interactions (additives, synergistic, antagonistic) must be considered. The nature of adverse health effects can usually be determined from properly designed tried animal experiments or human epidemiological studies. Potentially toxic agents may also be identified by the use or short term or *in vitro* tests. Other methods of identification of potentially toxic agents include chemical structure similarity to known toxicants.

Attempts should be made to reduce the number of potentially toxic chemical contaminants, but the microbiological quality of drinking water must not be comprised.

- In general, no adverse health effects have been observed from the consumption of drinking water generated from a controlled public supply (i.e., adequate source protection, treatment methods and distribution system) and which met drinking water standards. Nevertheless potential hazards exist.

- Epidemiologial studies should be encouraged, but only when they are expected to be of a sensitivity sufficient to detect the predicted effect or when they are clearly acknowledged to be hypothesis generating in intent. The most rigorous methods and standards of design and interpretation must be used.

- When estimating hazards of chemicals to humans, it is essential to consider exposure from all sources (air, food, water, occupational exposure, lifestyle, etc.). In general, drinking water is a minor source of total daily and lifetime exposure to most environmental chemicals.

- Where risk of toxic effects is estimated for various levels of exposure, the acceptance of a particular level of risk is a socio-political judgement.

- A means for monitoring the toxic potential of the chemicals in tap water in a rapid and comprehensive manner should be sought. Studies aimed at the development of simple assay methods are strongly endorsed. Similarly, a flexible and reliable strategy for the application of such methods should be developed.

- The NATO/CCMS Master List of Organic Chemical Contaminants should be kept current. Participation by all NATO countries is strongly encouraged. Study of the role of chemical constituents in potable water in the etiology and expression of human disease should concentrate on those where they may be factors in common diseases (for example, cardiovascular disease, cancer), should be considered as part of the overall strategy of disease investigations and should deal with possibilities of benefit as well as harm.

### Area V, Reuse of Water Resources,

Albert Goodman, Chairman

The reuse study group examined current practices in the direct or indirect recycling of water for potable use from a number of aspects, including the regulatory and legislative control of discharges of pollutants to surface waters in the participating countries, the different methods for assessing the percentage of indirect reuse, the purification systems which are available for reuse applications, the health aspects associated with both direct and indirect reuse, the non-potable applications of reused water, the public acceptance of renovated wastewater, and the trends in water resources management with respect to reuse. Several case studies involving indirect reuse were presented. As an adjunct to the study group report, the proceedings of a workshop entitled, "Protocol Development: Criteria and Standards for Potable Reuse and Feasible Alternatives" are included in the report appendix. The latter, a contribution by the United States Environmental Protection Agency, with participation by representatives of local, State, federal and international government agencies, consultants and universities, contains presentations on reuse aspects of toxicology, chemistry, microbiology, engineering, ground water rechange and non-potable applications, as well as on the broad issues of water reuse. The final section of the proceedings highlights a panel discussion on the question of future direction for examination of the feasibility and practicality and safety of potable waste water reuse.

The potential health risks of direct potable reuse are not fully understood. In particular, there is a need to learn more about the effects of long-term exposure to low levels of contaminants. Until there is more scientific information on this subject, direct reuse cannot be judged safe for drinking water and should be avoided. Where water demand outstrips existing supplies, direct reuse should be reserved for low order uses; dual water systems may be considered where feasible. Performance reliability of reuse systems is essential to practical consideration of potable reuse.

Current drinking water standards have not been formulated on the expectation that significant direct reuse would occur. These existing standards are not directly transferable to direct reuse situations.

Not only surface waters are subject to a degree of indirect reuse. Ground waters also receive percolates from where industrial or domestic aqueous wastes are disposed on the surface of the soil. While the situation is usually not now serious, it can no longer always be assumed that ground waters do not require treatment, as increasing incidents of ground water contamination are being detected in many countries. Some specific treatments may be required to eliminate, as far as possible, organic compounds, particularly those used as solvents, and some metals which are often natural contaminants.

There is little direct evidence of the maximum percentage of indirect reuse that should be considered safe under normal circumstances. "Safe level" of reuse are a function both of the percentage of reuse and of the time interval between use and reuse (during which a degree of self-purfication occurs). Nevertheless, prudent standards might strive for a maximum of 25% indirect reuse under most conditions.

On the basis of their survey of present practices, the Reuse study group concluded:

- The indirect reuse of surface waters must carefully managed to ensure the maintenance of the water quality of the source monitored to ensure that the percentage of reused water in abstracted supplied is kept at acceptable levels.
- Existing technology is capable of protecting consumers of reclaimed water from known dangers; however, the knowledge regarding the toxicity for the wide range of chemical and microbiological contaminants is limited.

- The most important argument against direct potable reuse is the lack of knowledge regarding the toxicological effects of the innumerable organic and inorganic chemical contaminants found in wastewater.

- The economics of treating wastewater for direct reuse are not generally attractive when compared to the cost of conventional sources of potable water, but when conventional sources are limited, reuse may be a competitive alternative.

- Water should be reused first for industrial, agricultural and recreational purposes.

- Reused water should be used for potable supply only as a last resort.

The Potable Reuse workshop generated the following conclusions and recommendations:

- A single set of drinking water standards should be developed for all waters regardless of source.

- A thorough characterization of potential source waters for chemical and microbiological constituents should be accomplished.

- A major effort should be made to examine the unknown or inadequately known organic fractions and a data base developed.

- Toxicology/concentrate studies may prove to be the logical tool for decision making instead of complete chemical analyses and synergistic studies.

- There should be no detectable pathogenic agents in potable reuse water.

- Any ground water recharge system which might result in increased contamination of the ground water should be tried only for research and demonstration purposes.

- Non-potable options should be considered ahead of potable reuse.

## Area VI, Ground Water Quality Considerations,

Dr. Horst Kussmaul, Chairman

The ground water study group examined the following aspects of ground water quality:

- Sources of ground water pollution
- Changes in water quality during underground travel
- Artificial recharge
- Ground water protection

### Ground Water

Ground water forms an important drinking water source in all the NATO countries. Ground water has many advantages over surface waters as a source of supply, such as normally consistent good quality, local availability and low treatment cost. However, the increasing rate of ground water withdrawal and the spread of urbanization have resulted in a reduction of both the quantity and quality of the available ground water in some areas.

The major source of ground water recharge is rainfall infiltration through the overlying soil zone, with smaller contributions from induced recharge (from surface water bodies) and from of water through the unsaturated zone changes its chemical composition. Models have been used to project the effect of underground travel on water quality and the nature and extent of pollution, bu the mechanisms controlling pollution movement through aquifers are as yet not fully understood.

Ground water can become polluted in many ways. Some of these are disposal of domestic and municipal wastes, discharge of untreated or partially treated sewage effluent, leaky sewers, leachates from solid waste disposal sites and disposal of municipal sludge to landfills. Other sources of contamination are the disposal of industrial wastes, both solid and liquid, and accidential spillage.

The study group concluded:

- The prime concern for the future should be to retain ground water quality and to control actions which may lead to the deterioration of natural good quality ground water so as to render it unacceptable for its intended use.

- In order to achieve ground water protection, more knowledge is needed on the pathways of natural recharge of aquifers, the persistence or attenuation of pollutants in the unsaturated zones of aquifers, the persistence or attenuation of pollutants in saturated zones and the natural distribution of chemical and biological constituents in ground water.

- A suitable data collection system is necessary to monitor ground water quantity and its possible changes with time.

The study group recommended the following areas for future research:

- Studies should be conducted on the natural variations in ground water quality and how these depend on input, flow, interactions and the influence of microorganisms.
- Studies should be conducted on the movement of individual organic and inorganic constituents of ground water.
- Studies should be conducted on the effects of flow through saturated zones on degradable and water-soluble substances.
- Studies should be conducted on the absorption capacity and other properties of strata relevant to persistent chemical substances.
- Studies should be conducted on the changes in the constituents of ground water flowing through different rock types by the use of laboratory simulations.

- Studies should be conducted on the effects of biological and chemical clogging acquifers.
- Studies should be conducted on improved methods of abstraction from, and recharge to, aquifers.
- Studies should be conducted on the residence and passage of time of bacteria and viruses in ground water required to achieve removal and/or disinfection
- Studies should be conducted on the potential impact of urban, industrial and recreational activities on ground water development.

Consideration should be given to the development of comprehensive strategies for the protection of ground water sources. The goal of the strategy ought to be to assess, protect, and enhance the quality of ground waters to the levels necessary for current and projected future uses and for the protection of the public health. One of the objectives of a ground water protection strategy is to provide a process whereby individual government and the public can set priorities among competing activities which may use or contaminate ground water.

# CHAPTER II

# INTRODUCTION

## Drinking Water Problems - Initiation of the Drinking Water Pilot Study

The Committee on the Challenges of Modern Society (CCMS) was created in 1969, the same year the North Atlantic Treaty Organization (NATO) celebrated it twentieth anniversary. The committee's function is to explore ways in which the experience and resources of the Western nations can most effectively be used to improve the quality of life. The committee is part of NATO's third dimension - a social dimension that joins a strong military dimension and a profound political dimension. The CCMS program consists of pilot studies on topics proposed by the member countries.

At the Spring CCMS Plenary in Dusseldorf, Federal Republic of Germany, on February 8-9, 1977, the United States proposed a Pilot Study on Drinking Water for adoption by the NATO Committee on the Challenges of Modern Society. The United States, through the U.S. Environmental Protection Agency's Office of Drinking Water offered to serve as pilot country for the study and all the Allied nations were encouraged to participate actively.

The problem of providing potable drinking water that is bacteriologically and chemically safe, as well as esthetically acceptable, is becoming considerably more complex, particularly in industrial nations. As the quantity of available water resources is reduced by population growth, urbanization and industrialization, the availability of clean, uncontaminated water for human consumption also declines.

Providing safe drinking water in industrialized nations present considerably different problems than are usually encountered in developing countries, where supply and microbiological quality are the major concerns. Industrialized nations have generally been able to control waterborne disease transmission, as evidenced by the extremely low incidences of typhoid and chloera since the advent of widespread disinfection practices. But new and potentially serious questions are raised for all nations by the proliferation of industrial chemical discharges into drinking water sources by urban runoff, by water polluted with human waste (both treated and untreated), contamination of ground waters with industrial chemicals because of inadequate waste disposal practices, and finally by the formation of new chemicals in drinking water from the interaction of disinfectant chemicals like chlorine with the natural chemicals commonly present in drinking water.

The United States submitted the initiative for the new pilot study in the hope of achieving a better understanding of the drinking water problems that are shared by all countries and of the solutions to these problems. The pilot project was planned to provide the most up-to-date information on the possible technological approaches for dealing with the problems.

The proposal was presented in preliminary form in the 1976 CCMS Plenary meeting in Brussels. Subsequently, experts from nine Allied nations met in December 1976 and prepared a detailed revised outline of the project. The outline cut across the major generic subjects of water supply technology and included analysis and detection of pollutants, instrumentation, microbiology, treatment processes, engineering, health science, data handling and dissemination, water reuse and ground water problems.

It was neither appropriate nor possible to design and carry out each subject area with the same degree of detail. Some of the topics were highly technologically oriented, whereas others concentrated on surveying prevalent thought and activities in various countries.

The aim of the proposed pilot study was to produce comprehensive reports on current problems relating to drinking water in the participating nations. The report would include evaluations of existing technology and practice from the points of view of effectiveness, public health protection, practicality, costs, general availability, and associated by-product hazards. The project would also explore emerging technology and make recommendations for further technical efforts. Furthermore, identifying ongoing activities and disseminating information between participants allows national programs to focus on specific areas of water supply research without duplicating work being done elsewhere. This also encourages national adoption of the most up-to-date technologies and practices.

The pilot project group invited involvement from other international organizations such as CEC, OECD, and WHO, to assure that overlaps would be avoided and benefits maximized.

The United States believed that drinking water problems would be an appropriate issue to be treated by CCMS since the problems are common to all the Allies. It was particularly timely, and all would be able to benefit from a more detailed understanding of how each of them has dealt with the issues affecting water supplies.

The following work program was considered for the Pilot Study although modified as the study proceeded.

I. Analytical Chemistry and Data Handling

A. Monitoring Methods and Standard Testing Procedures

1. What is being analyzed
2. How is it being analyzed
3. Mandatory or recommended
4. Frequencies
5. Publications and cooperative activities

B. Automated Process Control and Stream Monitoring Technology and Methods (Sensors and Telemetry)

C. Data Handling and Resolution

D. Use of Data in Decision Making

E. Information Format Design

II. Advanced Treatment Technology

A. Technology Description

1. Activated carbon (powdered and granular), carbon and ozone, and reactivation

2. Other adsorption media (sand and resins)

3. Disinfection treatment

4. Others (desalination, ion exchange, flotation and flocculation technology, denitrification)

5. Membrane treatment (osmosis and electrodialysis)

B. Evaluation of Technology

1. Cost data (capital and operating)

2. Effectiveness of each technique in removing the element targeted for removal

3. Quality of treatment chemicals

4. Residues and byproduct formation

C. Emergency response measures when appropriate

III. Microbiology

A. Sampling and Assessment (monitoring frequencies, indicators, etc.)

B. Treatment Modification and Variation in Risks from Bacteria and Viruses

1. Reduction of quantity of disinfectant and results of reduction

2. Build-up of endotoxins from adsorbant use

IV. Health Effects

A. Significance of Contaminants to Human Health

- 1. Identification and Concentration of Contaminants
    - (a) Chemicals (organic and inorganic)
    - (b) Microbiological (bacteria, virus, protozoans)
    - (c) Particulates (asbestos, turbidity)
- 2. Location of Contaminants
    - (a) Raw water
    - (b) Distribution systems
    - (c) Treatment process

B. Health Effects Evaluation of Contaminants in Drinking Water

- 1. Waterborne Disease
- 2. Toxicology (protocols) for assessment and current activities)
- 3. The role of Epidemiological studies (prospective and retrospective); identifying populations for future studies

C. Contaminants and their levels of seriousness

D. Information Format Design

V. Reuse of Water Resources

A. Epidemiological Aspects of Reuse

B. Appropriate Treatment Technology for Various Reuse Situations)

C. Composition of Recycled Water

VI. Ground Water Considerations

A. Protection

B. Recharge

C. Other

The Committee on the challenges of Modern Society approved the United States proposal for a drinking water pilot study and on March 1, 1977, the Chairman of the Committee (Joseph M.A.H. Luns) issued the following note:

> In approving the proposal, the Committee noted that this would be the most comprehensive study ever undertaken on this subject, and that a number of member countries would participate actively. The objective of the pilot study is to achieve a better understanding of the drinking water problems that industrialized countries share and to seek solutions to them. The study will include evaluations of existing technology and practice from the points of view of effectiveness,

the public health protection, practicality, costs, general availability and associated by-product hazards.

Although certain aspects of the drinking water problem are under study in other international forums, no other organization has undertaken a study of this comprehensive nature. In order to avoid any duplication from the outset, the Commission of European Communities, which is also doing work in this area, participated in the expert meeting held in December last year, where the detailed work programme was prepared. The CEC, as well as other interested international organizations, will continue to be invited to expert meetings of this pilot study in order to ensure co-ordination of any on-going work.

The United Kingdom and the Federal Republic of Germany were named as copilots for the study. Leadership of individual topics was accepted as follows:

Analytical Chemistry and Data Handling - United Kingdom (Laurence R. Pittwell)

Advanced Treatment Technology - Federal Republic of Germany (Prof. H. Sontheimer)

Microbiology-United States, (Prof. Dean O. Cliver)

Health Effects - United States, (Prof. Joseph Borzelleca)

Reuse of Water Resources - United Kingdom (Albert Goodman)

Ground Water Considerations - Federal Republic of Germany (Dr. Horst Kussmaul)

Each of the study groups prepared a final report, except for Area II, Advanced Treatment Technology. The latter group's report is in the form of the proceedings of two symposia - one on oxidation techniques and the other on adsorption techniques. The completed project has taken the form of an extended series of published volumes, as follows:

Area I. Laurence R. Pittwell, United Kingdom, Chairman

- Analytical Chemistry and Data Handling

Area II. Prof. H. Sontheimer, Federal Republic of Germany, Chairman

- Oxidation techniques in Drinking Water Treatment (Karlsruhe)
- Adsorption Techniques in Drinking Water Treatment (Reston, Virginia, USA)

Area III. Prof. Dean Cliver, United States, Chairman

- Microbiology

Area IV. Prof. Joseph Borzelleca, United States, Chairman

- Health Effects
- Drinking Water and Cardiovascular Disease (proceedings of a symposium held in Massachusetts, USA)
- Proceedings of a Symposium on Water Supply and Health (Netherlands)
- Humic Acids in Water (Norway and USA)

Area V. Albert Goodman, United Kingdom, Chairman

- Reuse of Water Resources (includes proceedings of U.S. EPA Water Reuse Workshop)

Area VI. Dr. Horst Kussmaul, Federal Republic of Germany, Chairman

- Ground Water Considerations

# CHAPTER III

## AREA I

## ANALYTICAL CHEMISTRY AND DATA HANDLING

## SUMMARY

LAURENCE R. PITTWELL, UNITED KINGDOM, CHAIRMAN

The report is chiefly a survey of present practice and problems in interested nations, the parameters and frequency of monitoring, the analytical and sampling methods used, and the national analytical quality assurance procedures, though no details of the latter are given. Consequent problems in the choice of methods are discussed. Factors influencing such choices are:

i. Range required;

ii. Degree of accuracy required;

iii. The speed and frequency with which results are required;

iv. Interferences;

v. Equipment available and labor required;

vi. Sample stability and sample utilization; and

vii. Local legislation on the use of chemicals.

Information is also given on the legislative aspects, testing the suitability of materials, and on applications of data processing.

## The Need for Monitoring

The ultimate aim of chemical analysis in the Drinking Water Industry is to provide data to safeguard the quality of water intended for consumption or used in cooking and cleaning.

Water pure enough to drink without any treatment at all is becoming scarce. Much of the available water contains some quantity of sewage or factory effluent the degree of treatment of which varies from negligible to very thorough. Even when there are not such effluents, risks may still be present. Several epidemics have been traced to infection from wildlife in the catchment area; pesticide and herbicide spraying of upland catchments is not unknown and there is often the possiblity of chemical spillage during transport, even in remote aras. Preparation of safe water under such circumstances can be a complex operation which needs adequate analytical control throughout the process to the final product. Distribution systems ought, ideally, to be capable of delivering water to the consumer in the same state in which it was discharged from the waterworks, but water is a reactive solvent quite capable of leaching trace amounts of material from the pipework and equipment; furthermore, for convenience and protection in inhabited areas, distribution systems are buried underground and so are liable to serious contamination in the event of a break in the pipe.

In consequence, if public health is to be safeguarded, the minimum requirement for even the purest water is a periodic check of the quality of the incoming water as well as the water at the consumer's tap. Most water supplies will require more efficient monitoring than this, depending first, on the usual quality of the incoming water and the risks to which it is exposed; second, on the complexity of the treatment required; and third, on the distribution system.

Experience has shown that standards of quality inspection vary, dependent on the skill and experience of the analyst and the equipment available. It is, therefore, advisable for the appropriate authorities to monitor the various water quality control laboratories and their sampling programs to ensure that the control is adequate.

Before embarking on the design of a new water installation, a thorough analysis, both of the quality of water available and of potential risks to the catchment area, will be of use in designing the plant and in establishing the routine monitoring program.

Records of analyses are useful for detecting seasonal or continual trends in water quality which can be used as guidelines for plant control purposes. Such records can also be used to help assess the adequacy of the existing plant and decide when additions or replacement will be required. Adequate care of records is, therefore, necessary.

## Monitoring Requirements

Monitoring must be adequate enough to assure consumer protection and the results must be obtained in time to be of use. The monitoring procedures used must be tailored to the individual raw water and treatment process, and the analyses must be of assured quality. These requirements present a problem for which the ideal solution is often impossible or impracticable. Many of the specific determinands are complex substances present in a mixture of similar substances requiring separation and purification prior to identification and quantification. Such analytical processes often take much longer to carry out than the complete process of water treatment, so that by the time the analysis of the raw water is available, the water may already be in the distribution system, and is often consumed before the finished water leaving the treatment plant has been analyzed for the more specific determinands. Consumer's tap samples are almost always received too late for any remedial action, but are usually the only safe practicable way of controlling quality in the final stages of the distribution system. Rapid general tests such as chlorine residual measurements are, therefore, necessary for the routine control of water quality. These tests need to be related to the specific determinand and periodic checks should be made to ensure that their relationship is still valid.

Although rivers are capable of a degree of selfpurification (by action of a substance with the riverbed, the river itself, or with organisms in the river), it is easier to detect potential hazards by analysis of waste effluents at the point of discharge, where the concentration of contaminants will be far higher, than at the point of abstraction. Due allowance will have be be made for the effects occurring within the river, but at least the waterworks will have warning of what to expect in its incoming raw water.

Rivers are usually far from homogeneous, especially in the vicinity of confluences or discharges, and thorough mixing may take quite a considerable distance. At the same time, variation in flow rates in different channels round islands, reactions with the bed, and other variables can further complicate the pattern, so that it is often impossible to predict the representativeness of a sample point without considerable testing to establish a flow and load profile and its variability to river conditions. Even ground waters can vary in quality with time and depth in the aquifer. Yet, however carefully such a program is carried out, it can rarely safeguard against an accident unless the sampling is continuous and truly representative.

On the other hand, money is not unlimited, thus, the sampling and analytical programs used must be a compromise designed to give the best available protection with the funds available.

### Data Handling Requirements

Most of the information from monitoring is immediately used for control purposes. There is no need to store all of this information, but a suitable record should be kept of trends for long term assessment of supply operations. In addition, it is possible, by use of continuous and semicontinuous monitoring devices, to have a degree of automatic process control.

Public access to a summary of the available data is desirable as a means of reassuring them, or alerting them to the need for improvement.

Besides keeping a record of the actual results, it is essential to keep a record of the method used to obtain them. This will allow subsequent assessment of their worth, should their validity be questioned.

## Requirements for the Future

Future requirements for analytical method development cannot be accurately predicted on a long range basis. Much depends on trends in treatment process development, both for drinking water and for effluents discharged above abstractions or leaking into aquifers. Much also depends on future developments in public health and analytical methods research. There are, however, some identifiable needs:

i. There is a need for quicker, cheaper methods of quality control, even if these methods are empirical, especially when a full determination of the factor being controlled requires a semi-research type analytical procedure.

In such cases, there is also the need to correlate the two determinations locally.

ii. Further attention should be given to continuous monitoring methods, especially for incoming water quality and process control operations. Use of automated methods should be extended, as such methods not only save manpower, but are often of greater reproducibility than manual methods provided the accuracy and limit of detection are sufficient.

iii. Methods are needed for the rapid identification of trace substances in water, especially, the 80% of non-volatile organic matter; however, there is little point in identifying increasing numbers of microtrace impurities unless there is an indication that a real hazard exists.

While hundreds of organic chemicals have been identified in some waters at nanogram levels, little attention has been paid to the humics, fulvics, and lignins that constitute the bulk of the total organic content.

iv. Methods are needed for determining the actual forms in which several substances, currently reported as total substances, may be present. Toxicity often varies with the form in which a substance is present, thus, when interconversion is slow or negligible, the form in which it is present may be important.

v. Sampling methods and storage or preservation still need further study. There is no point in carrying out an expensive analysis on a sample which is not typical of the material being analyzed or in which the determinand has decomposed during transit or storage.

vi. Laboratory technicians require adequate training, and supervision and periodic updating of skills.

vii. The equipment needed for the detection and quantification of some compounds in raw waters is scarce and expensive, so there is a need for cooperative use of such equipment. Few, if any, laboratories can afford to own every instrument they might possibly use.

viii. The working group considered mentioning certain specific determinands for which methods were inadequate, but so rapidly has analytical research developed and as equally rapidly have the analytical requirements changed, that the list of determinands requiring methods has completely changed several times while this report was being drafted. The group suggests, because of this, that information exchanges in the fields covered by their report should be arranged at intervals in the future.

Choice of methods presents a problem. Group I prefers harmonization of proven accurate methods, with the local laboratory at liberty to choose the method most suited to their needs. It is often impossible to choose one single method which will suit all water types, or which will suit every laboratory situation. Futhermore, use even of a method of proven accuracy does not completely guarantee the accuracy of the result. The harmonization test should be carried out by the actual laboratory using the method, and include samples of a type similar to their own raw water. Thereafter, reliable analytical quality assurance procedures should be used.

Recommendations

i. Commensurate with the risk to health, water supplies should be monitored at or before the source or point of abstraction and, where practicable, this should be done in such a way that there is ample time for remedial action to be taken before the water is processed. Such monitoring should take into account the risks likely to be encountered by the consumers.

ii. Process control analyses need to be adequate to ensure that the quality of water leaving the waterworks is satisfactory and that, in addition, samples should be collected at representative points throughout the distribution system to assure that the water reaching the consumer is of the same quality.

iii. When the analysis for a specific hazardous determined is time-consuming or costly, an appropriate rapid empirical test should be devised and used routinely; but sufficient full determinations should be made at such regular intervals as will assure the continued validity of the control analysis.

iv. There should be adequate control of analytical quality both within and between laboratories. It is realized that interlaboratory tests are very difficult to organize in such a way that meaningful results are obtained, hence, such interlaboratory tests should be used sparingly but thoroughly.

v. Adequate performance characteristics on the reproducibility and reliability of analytical methods need to be obtained and published (accuracy, precision, limit of detection, bias, interference effects, etc.); the methods used for quality control monitoring also need to have adequate reliability. Because local variations in water quality may affect the interferenc effects; because of differences in equipment availability, laboratory work loads and sample types submitted, all of which affect the choice of methods; and because familarity with a method enhances reliability of results provided harmonization tests show that the test data are adequate;

laboratories should be free to use acceptable methods of their own choice.

vi. Adequate tests should be made using local waters to ensure that pipes and other equipment are made from materials suited to the water. Care may be necessary when making these tests to allow for variations in water quality, either with season or when several types of water are supplied to a grid network.

vii. Adequate records of water quality data need to be kept and should include information on the analytical method used. These should not be a complete record of all analyses, but should indicate trends and variations. When planning such a system, provision for the possible use of such data for control purposes, and for international data exchange, should be made.

viii. Exchanges of information, such as are given in the full report, should be made periodically.

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# CHAPTER IV

## AREA II

## ADVANCED TREATMENT TECHNOLOGY

## SUMMARY *

PROF. HEINRICH SONTHEIMER, CHAIRMAN

During the past ten to fifteen years, water treatment technology has changed considerably. Many improvements have been made such as the use of multilayer filters for more efficient and economical filtration, and important changes have been introduced regarding new concepts of process design, especially in conjunction with more frequent use of technologies such as oxidation and adsorption. There are two important reasons for the incorporation of such methods in the treatment process. First, analytical methods have shown that many surface waters are polluted with potentially hazardous organic chemicals that cannot be removed effectively by standard treatment methods. Second, breakpoint chlorination, while in many respects effective from both technical and economic viewpoints, has certain significant disadvantages. Through the reactions of free chlorine with organic constitutents, chlorinated organic compounds such as chloroform are formed. This can occur under conditions necessary for safe disinfection of the drinking water if precursor organic concentrations are high, and can lead to certain health risks, especially if these contaminants have formed in higher concentrations.

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It is becoming obvious in many countries that the standard treatment scheme is inadequate for future treatment of surface waters because the problems posed by organic contamination and breakpoint chlorination cannot be solved.

The standard treatment sequence consists of breakpoint chlorination, flocculation, sedimentation, filtration, and safety chlorination and pH adjustment. This treatment method provides a low turbidity drinking water, and satisfactory removal of ammonia even at low temperatures. There is a reasonable certainty that the drinking water at the consumer's tap does not contain excessive numbers of pathogenic bacteria or viruses, and this generally indicates a safe drinking water. The standard process is easy to operate and sensitive to water quality changes, and there is abundant experience available concerning the operational aspects of this type of treatment. This treatment process is still being used internationally by numerous waterworks, sometimes with certain minor changes, but normally with success.

Consequent to observations by many waterworks in Europe and North America indicating the serious disadvantages inherent in the standard treatment process for many types of water, studies were initiated in several countries under the auspices of the NATO/CCMS. A number of innovative treatment schemes have been tested in pilot plants and in large waterworks.

The alternate process schemes being proposed are often very different from each other, and the results of the research work have clearly indicated that no single treatment process combination can be substituted universally in place of the standard treatment. The special conditions at the plant, the surface water quality, and the type of pollutants encountered all must be considered to determine the optimal treatment method and process combination for each case.

After intensive discussions of current drinking water treatment problems native to the different countries participating in the study, it became obvious that the best way to present all of the available knowledge and experience would be to organize two international conferences.* During the course of these meetings it became apparent that two types of processes offer the greatest promise of solving potable water treatment problems. These processes are (1) oxidation processes using chemical oxidants such as ozone or chlorine, or biological oxidation alone or in combination with chemical oxidants; and (2) adsorption processes, especially those using granular activated carbon filters, and often combining adsorption and biological oxidation. This paper represents an overview of the salient points of the two conferences with regard to the utilization of oxidative and adsorptive treatment processes. The intention of this discussion is not to prescribe general rules, valid in all cases, but rather to draw attention to the potential benefits to be obtained and the problems remaining to be solved.

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* The results of international studies concerning the state-or-the-art of the application of oxidation and absorption techniques (including granular activated carbon) in the treatment of drinking water were presented at two separate conferences - the first held in Karlsruhe, Germany in September of 1978, sponsored by the Federal Republic of Germany and the second in Reston, VA, April 30-May2, 1979 - sponsored by the Environmental Protection Agency (EPA) and the North American Treaty Committee on the Challenges of Modern Society (NATO/CCMS). Participating countries were Belgium, France, Federal Republic of Germany, United Kindgom, the Netherlands, Switzerland and the United States.

## Possible Changes in the Standard Treatment Process

It is obvious that the treatment of surface waters for drinking water purposes must include flocculation and filtration and, in most cases, intermediate floc separation by sedimentation or flotation. Potable water must have a low turbidity and should be low in colored substances. Both criteria can be achieved with the processes mentioned above; in this respect the standard treatment scheme remains unchanged.

However, in order to avoid possible disadvantages of breakpoint chlorination, additional treatment steps may be required to achieve better removal of micropollutants and a greater reduction in the overall organics concentration. This is currently the most important problem in drinking water treatment and is the central issue of discussion. Other problems such as high concentrations of heavy metals or nitrate are less widespread, and although they must be considered as they arise are not included in this summary.

## Pretreatment Before Flocculation

When using the standard treatment procedures, breakpoint chlorination is usually the only pretreatment employed. Aside from ammonia oxidation, this pretreatment normally promotes a better operation of the flocculation and sedimentation units by hindering an aerobic decomposition of the settled sludge and biological growth within the operating units.

Many studies have been conducted on how to avoid the drawbacks of omitting breakpoint chlorination on the one hand and to achieve better treatment results after flocculation and sedimentation on the other. The best course to adopt depends largely on the quality of the raw water, so general rules valid for all cases cannot be made. Several alternatives to pretreatment are worthy of consideration.

Pretreatment by means of storage basins. The most important advantages of this well-known and widely used process are the removal efficiency for suspended solids and the biological purification that takes place within such basins. Problems that can occur as a result of this type of pretreatment are anaerobic decomposition of the settled sludge and growth of algae. Some waterworks have found limiting the retention time to two to three days and increasing the pH via lime dosage to be useful in avoiding these problems. If placed properly in the treatment process and operated correctly, storage basins or ponds can be very helpful for improving the raw water quality.

Prechlorination with dosages under the breakpoint. The formation of chlorinated organic compounds can be avoided if chlorine dosages are controlled so that any chlorine residual is in the form of chloramines rather than free chlorine. According to experience this can best be achieved by controlling the chlorine dose in proportion to the results of continuous monitoring of the ammonia concentration. Changes in the concentration and composition of organics in raw water also affect chlorine demand, but the changes usually do not lead to high amounts of chlorinated substances in the water, so long as the chlorine residual is maintained in the combined form.

More important for this type of treatment was the observation that complete ammonia oxidation can be achieved in carbon filters following flocculation, sedimentation, and filtration. Sometimes a stepwise addition of chlorine can be helpful for ease of control.

Pilot plant data have shown further that such pretreatment increases the permissible run time of granular activated carbon (GAC) filters between regenerations by promoting intensive biological regeneration within the filters. These effects are very similar to those of ozonation, which can be used at this point in addition to prechlorination. If this procedure is used, ozone should be applied after flocculation.

Until recently very few studies have been performed on this type of pretreatment, which can be used in connection with storage basins. Additional pilot plant and full-scale studies are necessary to gather data for this promising treatment step.

Preozonation before flocculation. Tests with different waters have shown that preozonation can improve flocculation efficiency. Dosages necessary for this type of treatment are usually in the range of 0.2 to 1.0 $g/m^3$, optimal dosage for most waters must be evaluated experimentally.

Frequently preozonation is combined with the removal of the residual ozone in the offgas of main ozonation basins, thus enhancing the overall efficiency of ozone utilization. Preozonation sometimes enhances biological oxidation in the flocculation plant, too, especially when sludge blanket clarifiers are used.

Riverbank filtration. This well-known way of withdrawing river water also serves a pretreatment function. It can be used only in cases where hydrologic conditions permit and usually has more advantages than disadvantages. The advantages include a 50-75 percent reduction of dissolved organic carbon (DOC), substantial removal of heavy metals pathogenic bacteria and viruses, which more than compensate for the potential disadvantages such as dissolution of iron and manganese. Instead of riverbank infiltration, spreading basins or other techniques for ground filtration can also be used.

The degree of disinfection attained by the pretreatment processes discussed here, as well as by other methods such as microstraining, is lower than with breakpoint chlorination. This can lead to problems in controlling some microorganisms in the subsequent treatment and will have to be controlled by means such as more frequent backwashing of the filters.

It is obvious that pretreatment is not necessary in all cases and for all raw waters, but the processes discussed often enhance finished water quality.

### Disinfection and Oxidation

When omitting breakpoint chlorination, and thereby losing its contribution to disinfection, another treatment step where reliable disinfection is achieved through chemical or biological oxidation should be used to ensure a safe drinking water. There are many different possibilities for this purpose whereby the same oxidation process can be used at different points in a treatment train.

**Ozone disinfection.** Many studies have been made and ample experience is available for the use of ozone to inactivate viruses and to kill bacteria. Ozone treatment has been used (most notably in France) as a final treatment step prior to safety chlorination to ensure wholesome and safe drinking water. A residual ozone concentration of 0.4 mg/L is maintained over a 5-min retention time. Recent studies have shown that when treating water of low turbidity, the necessary time for disinfection, especially for virus inactivation, can be much shorter.

While there is excellent practical information available on this type of treatment, some problems have been encountered. Ozone oxidation leads to a change in molecular weight and structure of the organic substances, resulting in higher biodegradability and faster bacterial growth in the distribution system. As a result the required postchlorination dose must be increased. These changes in the composition of residual organics may have other effects that have yet to be recognized.

Recently, more and more waterworks have taken advantage of the efficient disinfection and higher biodegradability through ozonation by changing the point of application in the treatment train. Ozone oxidation can be used after flocculation and sedimentation, prior to filtration, or after the sand or multimedia filters, if granular activated carbon filters are the subsequent step. By this mode of operation biological oxidation of the degradable substances within the filters can be promoted. This avoids excessive bacterial growth in the distribution system and allows better organics reduction. The combined chemical and biological oxidation processes, often used together with adsorption, seem promising. This can be concluded from many pilot plant results and from the positive experience gained in waterworks using the processes.

There are still many unanswered questions concerning this process combination that can only be answered by further research. As a first step, pilot plant studies should be conducted on different types of raw water to find the optimal process conditions. The dependence of process performance on design and operating factors and raw water composition are not yet fully understood. Biological oxidation can also be carried out in low sand filters or during ground passage, a combination that may become more widely used.

Biological treatment. Slow sand filters and ground infiltration have been used successfully in potable water treatment for more than 150 years. Recently it has been found that similar results are obtained by biological treatment in granular activated carbon filters. Aside from organics and turbidity removal, properly operated biological treatment also is effective in disinfection. Moreover, only a slight amount of chlorine or chlorine dioxide is required for safety disinfection after the biological treatment.

The most important disadvantages of biological treatment are the large space requirement and, in some instances, the high operation costs for filter cleaning. Recent experience has shown that it is possible to operate slow sand filters at much higher filter rates (up to 1 m/hr) with good disinfection results, provided adequate pretreatment by flocculation and filtration is applied.

Sometimes it is advantageous to oxidize with ozone ahead of filtration, especially if combined with ground passage. Biological oxidation occurs not only at the surface of slow sand filters, but also within the ground. Ozonation can help in reducing the underground retention time required to attain a given degree of water quality.

Slow sand filters with high filter rates have proved successful, especially for removal of bacteria after biological treatment in activated carbon filters. Here the DOC and ammonia removal occurs mainly in the carbon filters, while the sand filters reduce the bacteria counts. The effluent quality provided by this combination is relatively independent of raw water quality changes and attains high finished water quality.

Although a very old process, biological treatment seems on the verge of becoming modern once again, especially in conjunction with GAC filters.

Disinfection at the end of the treatment process. After the removal of suspended, and part of the dissolved, organics, disinfection can be performed at the end of the treatment process with chlorine without formation of excessively high concentration of chlorinated organics. Chlorine dioxide also can be used for the same purpose, with the advantage that it remains longer within the distribution network. However, in some cases there may be increased turbidity at the tap if the distribution network includes old pipes coated with corrosion products. Chloramines also can be used as disinfectants. Practical data are available concerning the use of chloramines in treatment processes in the United Kingdom.

Generally, disinfection at the end of the treatment process can be as safe a practice as breakpoint chlorination if it is used properly after careful studies. There are no accepted general rules for deciding which chlorine species should be preferred for a given water. The special conditions in each case must be considered. For this purpose it is advisable to study the oxidation kinetics for each water and oxidant.

## Ammonia Removal

Many surface waters contain ammonia that must be removed during treatment. This can be accomplished easily and effectively through breakpoint chlorination, even at very low temperatures. If this treatment cannot be used, the only alternative for practical purposes is the biological oxidation of ammonia to nitrate, which can be a problem in rare cases where nitrate concentrations increase above the maximum permitted level.

Another problem lies in the slow oxidation rate at low temperatures, which leads to difficulties below 3°C. Under these conditions long reaction times are necessary. Ample reaction time is afforded in ground filtration, but difficulties may be encountered with conventional filters. This problem can be overcome to some extent through preozonation.

The most important processes used for nitrification are:

(1) slow sand filters,
(2) rapid sand filters,
(3) dry filters with air flowing in parallel with the water through the filter,
(4) filters with countercurrent flows of air and water,

(5) fluidized bed reactors, and
(6) granular activated carbon contactors.

Most of the processes are applied for nitrification only, but they also provide some other purifying effects. The removal efficiency for other constituents in the process may be decisive in choosing the optimal nitrification process.

Biological nitrification usually requires an acclimation period of two to four weeks or even longer to start full operation. Thereafter, problems may still arise through heavy metals, especially when treating the raw water directly. Therefore, in many cases, flocculation and filtration are necessary pretreatment steps to prevent heavy metals poisoning, especially if the metal concentrations fluctuate widely.

After the initial period, nitrification usually works without problems, if retention times are high enough and if the oxygen concentration and the pH are maintained sufficiently. The dosage of pure oxygen into the water has proved useful to maintain a minimum oxygen concentration at higher ammonia concentrations. It is important to note that aside from oxygen demand there is usually no competition between ammonia oxidation and DOC removal. But nitrifying bacteria grow slowly, and care must be exercised to avoid excessive losses when backwashing filters. Thus far, in most waters studied, preozonation enhances nitrification, so long as the residual ozone is removed; e.g., by a small layer of granular activated carbon. Biological ammonia oxidation works well in many waterworks, but care must be taken to assure a good plant operation, especially at low water temperatures.

## Adsorption on Activated Carbon

Activated carbon has been used for some decades in waterworks for taste and odor removal. The majority of waterworks have used powdered carbon, and there is a wealth of practical experience available for this type of treatment. The advantage of powdered carbon lies in the possibility of adjustment to type and concentration of the disturbing substances and in low investment costs.

Apart from powdered carbon, filters with granular activated carbon became more important during the last decade. This originates from the fact that very often it is necessary to remove organic chemicals other than those causing taste and odor. An interesting new development is the use of carbon filters for biological treatment in combination with the removal of hazardous synthetic organic chemicals.

While activated carbon filters have been used in some countries for more than 25 years, there is still widespread lack of knowledge concerning this important treatment step. Extensive research is now being conducted.

## Purpose and Design of Carbon Filter Plants

Filters for carbon treatment can be used for several purposes in drinking water treatment:

(1) removal of specific organics such as nitro- and chloro-compounds and aliphatic, aromatic, and polyaromatic hydrocarbons;
(2) reduction of TOC and chlorine demand;
(3) biological oxidation for ammonia and organics removal;
(4) taste and odor removal; and
(5) dechlorination.

Often, different treatment objectives are desired simultaneously, which may induce different optimum operation conditions. Therefore, proper design of an activated carbon filter plant is sometimes difficult. One well-known problem is competitive adsorption, sometimes leading to desorption of certain compounds and to an increase in their effluent concentrations. These chromatographic effects are among the reasons why haloform removal can be difficult, and costly with granular carbon filters.

Proper design of carbon filters calls for an exact definition of the treatment goal, and the evaluation and application of analytical methods well suited for the particular purpose. This is one of the reasons pilot plant work frequently will be necessary for obtaining design and process cirteria. Carbon tests usually are performed in such a way that the water to be treated is used in the procedure. Special methods have been developed for this in several countries. At the moment this type of study seems to be the only way to overcome the problems of design and operation of carbon filters. Pilot tests will also permit the study of possible biological effects, which are very important for filter running times between regenerations. Most tests with model substances have proven poorly suited as guides for design and operation of water treatment processes.

## Biological Treatment in Carbon Filters

Most carbon filters now used for drinking water treatment employ biological regeneration to achieve more economical treatment, in effect combining adsorption with biological treatment. This type of process is a natural one, as nearly always, after weeks of operation, microorganisms will grow in a carbon filter and oxidize biodegradable organics into $CO_2$ and $H_2O$. This leads to a reduction of the carbon loading and thus to a better carbon filter efficiency. The effectiveness depends on the quality and degradability of the organics in the treated water, the carbon quality, the empty bed contact time (EBCT), the concentration of the organics, and the relation of biogradable and nonbiodegradable substances. In most filters, 50 to 150g TOC per $m^3$carbon per day can be oxidized through microorganisms. Water throughput per cubic meter of carbon then can be two to five times higher without sacrificing water quality because of the regeneration effect.

The most important advantages of the combined biological and adsorption processes lie in their ability to maintain effluent quality in spite of the concentrations of impurities. There is always enough residual adsorption capacity if the biological efficiency is controlled by monitoring oxygen consumption and pH decline in the filters.

It should also be mentioned that biological oxidation in carbon filters can be enhanced by chemical oxidation using ozone or chlorine, if care is taken to avoid reaching the breakpoint when using chlorine. Usually, 0.5 g of ozone per g of organic carbon is necessary to achieve a good effect, but there is no general rule for this. While the ozone dosage can be changed very easily, this is not possible with chlorine, due to the need to avoid free chlorine with respect to haloform formation. Usually, optimum oxidant dosages have to be found in pilot plant studies or through investigations performed at full-scale plants.

## Control of Carbon Filters

Besides monitoring the biological efficiency of the filter, other analytical measurements should be used. One possibility is the use of UV absorbance or TOC, but they should be monitored only in cases where parallel tests have shown a relation to other more important analytical data such as dissolved organic chlorine (DOCl), or the concentration of defined substances. It is nearly impossible to to postulate rules for carbon filter control, filter design, and carbon quality that will be valid for all waters. The general guidelines that follow provide some information on the problem, but there are exceptions that depend upon the water being treated.

(1) Chromatographic effects in carbon filters should not produce conditions where the effluent concentration of a single substance or a group of defined substances of the same structure exceeds the inlet concentration. Very often chloroform or trichloroethylene are good substances to be used for such control.

(2) The overall reduction of organics can be controlled in such a way that the UV-absorbing substances undergo a reduction of at least 50 percent. This usually goes along with a DOC removal of 30-40 percent. If this criterion is observed, the removal of dangerous and toxic substances, with the exception of trihalomethanes, will be reasonably certain in most instances.

(3) Most raw waters contain certain types of organics that can be defined as typical of most surface water pollutants. These organics should be monitored by using specific analytical methods.

(4) Biological efficiency can be controlled by measuring oxygen depletion and $CO_2$ increase in the filters. This should be done as a control method for all carbon filters, as biological activity is important for most carbon filter plants.

(5) Activated carbon quality should be tested, preferably under typical conditions for the water that is to be treated. Spiking with selected specific organic contaminants may enhance the information obtained from the tests. Special methods have to be developed for this.

Although these guidelines cannot cover all aspects of carbon filter control, they do provide some information for decision making in specific instances.

## Reactivation of Granular Activated Carbon

The use of granular activated carbon filters implies carbon regeneration. This reactivation can be done by the manufacturer in central plants or at the waterworks. Several types of furnaces have been used sucessfully. It can be said with confidence that there are no difficult problems with this treatment step.

One of the most important aspects of regeneration is the need for a method to control the quality of the reactivated carbon, using procedures suitable to drinking water purposes.

## Other Treatment Processes for Organics Removal

Besides flocculation, oxidation, and adsorption a few other processes can be used for organics removal. They are discussed briefly. Macroreticular anion exchange resins can be used for the removal of humic acids. The contact times for this treatment are quite short. The used regenerant can be recycled several times, but a waste treatment problem still remains. This process can be helpful in special cases such as high humic acid concentrations.

Adsorption resins have also been tried for the removal of specific substances, e.g., for the removal of volatile organic chlorine compounds. Regeneration with solvents can lead to some problems.

Another possibility for the removal of volatile organics is aeration, used in conjunction with air cleaning through activated carbon and air recycling. This treatment can be very economical at higher concentrations of trace organics if adopted only when no nonpurgeable organics have to be removed from the water.

The final alternatives are membrane processes that combine the removal of organic and inorganic compounds. They will be effective if inorganic salts as well as high molecular weight organic pollutants have to be removed.

## Conclusions

The treatment options show that there are many possibilities for new types of processes using oxidation and adsorption in combination with established treatment processes. Presently, it is not possible to propose one preferred combination that can replace the standard treatment configuration. The situation is not bleak, however, as the treatment trains now proposed offer many possibilities to select a specific design for each treatment problem. This can aid the water industry in devising more effective and economical water treatment combinations to assure safe drinking water.

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# CHAPTER V

## AREA III

## MICROBIOLOGY

## SUMMARY

PROF. DEAN O. CLIVER, CHAIRMAN

Potentially the most significant constraint upon the scope of the microbiology project is that it was to address the drinking water supply problems of industrialized nations. As was stated in the introduction to this report, industrialized nations usually have large quantities of water or industrialization would not have been possible. Even so, the quantities of water may not be adequate to meet anticipated needs, and the quality of available water may be much degraded by prior use. It is well, at this point, to ask what distinctive features of water supply in industrialized nations are significant to microbiology.

A major feature is high daily per capita water use. Daily consumption of beverage water is physiologically determined: the body's water losses must be replaced, so the total daily use of water by ingestion is determined by the climate and the size of the population in both industrialized and developing countries. Other uses of water in the home, which tend to be larger in industrialized nations than in developing countries, include flushing of water carriage toilets and cleansing of food, clothing, the home, its contents, and its inhabitants. Outside-the-home uses that contribute to the highly daily per capita demand in industrialized nations include a variety of applications in commerce and industry, as well as the occasional use of water for fighting fires.

Where the volume of water used exceeds the supply, a "reuse factor" (e.g., perhaps 25 percent of the water available at some point in a certain river has already been used somewhere upstream) may be calculated. Some classes of water reuse are of far greater microbiologic concern than others. For example, human feces, and therefore the water used to eliminate them from a household, are the most significant sources of infectious agents transmissible through water. By contrast, the direct disposal of human waste into waterways that occurs in some parts of the world (either from ships and boats on the water or from unsewered communities along the banks) may decrease the calculated reuse factor, but increase the risk of waterborne disease. Other microbiologically significant components of used water include substances which may support the growth of organisms in the water and heat. Project Area V of this CCMS Pilot Study addresses the broader aspects of water reuse, but reuse must also be considered in the context of drinking water microbiology because the majority of the infectious agents that might be transmitted by drinking water derive from the human intestines and are carried by wastewater, in some proportion, into water that may serve as drinking water sources. The problem of preventing waterborne infectious diseases would be greatly mitigated if an appropriate, non-polluting alternative to the water carriage toilet could be developed; such a device would be accepted only if it met the esthetic standards now prevalent in industrialized nations. Otherwise, the protection of source waters demands that the wastewater discharges be carefully supervised and that wastes be treated and disposed of in a manner that permits water to be reclaimed as necessary. Many features of this problem are considered in Project Area V and, in the specific context of groundwater protection, in Project Area VI.

Topic A of the microbiology report concerns Raw Water. Every community or water supplier should, and ordinarily will, select the purest available source for use in drinking water production. Groundwater from a deep, protected aquifer may contain only a few microorganisms, none of which is of intestinal origin. Water of this kind may be used in both private and public supplies with little or no treatment.

Even then, chlorination may have to be used in public systems to avoid problems in distribution. However, really well-protected aquifers in some areas may lie at such a depth that they are not accessible to private users. The depth of an aquifer may be less of a problem where public water supplies are concerned, but the quantities of water available must be adequate to the community's needs, or less pure raw water will have to be used.

Groundwater is frequently discharged to surface waterways after use (and, one would hope, after treatment), but increasing efforts are being made to dispose of wastewater in such a way that the groundwater will be recharged. The success and safety of this method of water reclamation depend greatly upon the ability of soil to accomplish microbiologic purification of the water between the point of application and the aquifer or, at least, the point of abstraction; on the character of the soil; and on whether recharge is undertaken by vertical infiltration under the influence of gravity or by pressure injection directly into the aquifer. This artificial recharge must be done with extreme caution, for the microbiologic purification of water by soil is not a well understood process; and once contamination of a groundwater source has occurred, it is extremely difficult to correct. This is an area where a great deal of research is needed; until results are available, it will be prudent to treat wastewater that is to be used for groundwater recharge to a degree that does not demand too much of the purifying capacity of the soil. The introduction of viable organisms to an aquifer is not the only microbiologic concern in groundwater recharge. Some microbially-induced chemical transformations can lead to degradation of groundwater, and toxins liberated upon the death of microbial contaminants may also prove significant.

Surface sources of raw water are more difficult to protect from microbial contamination and will frequently support the growth of some of the organisms that may be introduced. Airborne contamination and runoff from adjacent land surfaces, in addition to discharged wastewater, may contribute undesirable organisms or nutrients to surface waters. Surface water quality may also be directly affected by human activities such as recreational swimming and boating, residence in houseboats, or navigation on waterways for commercial transport of goods. Under optimal conditions, microbial counts in lakes extremely rich in nutrients may exceed $10^6$ per ml. Many organisms in surface waters are capable of inducing undesirable chemical transformations. Photosynthetic bacteria and cyanobacteria (formerly called blue-green algae) can grow to high levels, given favorable conditions and adequate light. These bacteria, as well as the true algae, can induce off-flavors in water, bind large quantities of dissolved oxygen under certain circumstances, and interfere physically with water purification. Toxins produced by some cyanobacteria may also be significant to human health. It is clear that surface waters which serve as sources of drinking water need more rigorous protection than many of them get, but it is also clear that more research will be needed before the requisite protective measures are well understood.

Topic A also includes a survey of the microbiologic quality of at least some of the raw water in nine different countries. Not surprisingly, raw water quality is generally better where the source is groundwater and where it originates in less densely populated areas. Even in these situations, raw water quality is seldom so consistently excellent that one-step treatment can safely be trusted. Where raw water quality is poorer, more intensive treatment methods are generally employed. Finished water of adequate quality and safety can evidently be produced by a series of unit processes ending with disinfection; but the community served is, obviously, more vulnerable to any kind of event that might even temporarily interrupt treatment of the water before distribution.

Recommendations Concerning Raw Water

(1) More research should be done on the microbial ecology of groundwater.

(2) The microbiologic quality of source waters should be tested routinely, especially in those instances where the quality of the raw water is judged so good as to require only minimal treatment.

(3) Adequate measures to protect good groundwater and surface water sources are required, including provisions for proper implementation.

(4) Means of conveying good quality raw water to areas where source water quality is deficient should be investigated further.

Topic B surveys the specific Pathogens that may be transmitted through drinking water. Generally, these are infectious agents including bacteria, viruses, protozoa, and metazoa. The proximate source of these agents in water may vary, but most of them ultimately derive from the human intestines. Intestines of other warm-blooded animals are an alternate source of some waterborne agents infectious to humans; only a few of these agents are apparently capable of living free in the environment for extended periods of time.

Although the agents discussed are all of concern to human health, the majority of the infections caused by them are mild or asymptomatic. This fact tends to complicate the investigation of waterborne disease outbreaks, in that the majority of infections may go unrecognized unless intensive and wide-ranging laboratory testing, frequently of fecal specimens, is undertaken.

Although quite long periods of persistence in water have been reported for some pathogens, the aqueous environment is not generally a favorable one for human infectious agents. Physical and chemical factors, as well as competition or predation by better-adapted indigenous microbial species, combine to kill or inactivate pathogens in water with the passing of time. Other things being equal, higher temperatures and longer detention times favor the destruction of greater quantities of waterborne pathogens. However, it is important to note that most time-dependent death processes occur as logarithmic functions of time, so that the level of the dying agent, theoretically, never reaches absolute zero. This raises the dual questions of how sensitive a method must be for detecting a waterborne pathogen, and what significance to human health may be represented by some small residual level of a pathogen in water. These two questions may or may not be intimately interrelated.

It is often argued that, as difficult as pathogens frequently are to detect in water, there is no need to develop methods to detect them at levels below which they represent a threat to health. However, there are those who believe that no level of an infectious agent is so low as to be insignificant to human health and that sample-to-sample variation offers the possibility that water sent to the laboratory for testing may contain less contaminant than water that someone drinks from the same source, so there is no limit to the desired level of sensitivity in testing for waterborne pathogens.

Further research is needed both to determine the relative threat to human health that is presented by different levels of a pathogen in water and to develop more sensitive methods for detecting waterborne pathogens. However, there is also a need for simpler methods of detecting waterborne pathogens, in that more samples, tested by more laboratories, may eventually produce a more useful body of information, to aid in producing a safer supply of water, than would be testing of a few very large water samples by the few laboratories that are equipped to deal with them. Even if these were available, test for pathogens could not afford a basis for routine quality control in drinking water supply. Given the problems inherent in detecting waterborne pathogens, it is not surprising that microbiologic testing of water is focused, instead, upon indicators.

## Recommendations Concerning Pathogens

(1) Even where water is protected, as is true of many groundwater sources, disinfection is recommended. This is especially important where finished water is to be stored rather than being used immediately.

(2) Aftergrowth of opportunistic pathogens during distribution of finished water should be prevented by maintaining a disinfectant residual throughout the distribution network, wherever possible, especially in large systems.

(3) Testing for pathogens within the distribution water is appropriate: (a) after contamination is found to have occurred; (b) to trace the source of any outbreak; and (c) in analyzing disinfection efficiency.

(4) Given the lack of correlation between viruses and the bacterial indicator systems, more research on the antiviral effectiveness of various water treatment processes is needed.

(5) Mapping of waterborne outbreaks should be conducted in conjunction with epidemiological surveys of the population served by the water supply.

Topic C of this report deals with Indicator Systems, which are microbiologically-based quality control methods. Indicator systems already established in use are generally based upon enumeration of viable organisms on a selective basis. Some, but not all, of these indicators are supposed to correlate with the occurrence of fecal contamination and, implicitly, with the presence of enteric pathogens. The closeness of correlation between different established viable indicator systems and fecal contamination varies greatly. Where correlations are low, it is usually either because the organisms measured may include some that are not of fecal origin at all or some that are capable of proliferation in the environment outside the body. Another potential liability, where disinfection is practiced, is that the indicator organisms may be more sensitive to the disinfectant than are some of the enteric pathogens which might be present. In addition to indicators of fecal contamination, there are indicator systems that gauge water quality and others that serve to signal the presence of specific pathogens. Finally, there is always reason to wish for indicator systems that are more rapid or simpler to apply; such systems could permit more replication of tests.

These considerations led to the inclusion in Topic C of a survey of proposed alternate indicator systems based upon viable microbes, including coliphages and animal viruses, as well as a number of groups of bacteria. Some of these may eventually serve special purposes on a regular basis, but none is presently ready to supplant the "established" indicators for routine quality control in drinking water treatment and distribution. Other indicator systems surveyed are not based on determining numbers of viable organisms, or at least may not require incubation through many microbial generation times before results are obtained. Some of these alternate systems seem to offer significant potential for continuous monitoring of water quality in situations where rapidly obtained results will permit prompt remedial action. No system considered would obviate the need for proper sampling techniques or for adequately trained laboratory personnel.

Topic D surveys Testing and Standards for drinking water in various countries. For the time being, microbiologic quality control of drinking water, in most of the countries surveyed, is based upon the coliform group. However, in some countries, thermo-tolerant coliforms or *Escherichia coli* (based on a working definition of the species) are determined instead of or in addition to the coliforms. Procedures for both sampling and testing are seen to vary from country to country, but the differences are not so great that the coliform test results cannot be compared. The general intention in every case seems to be that coliforms (or thermo-tolerant coliforms or E. coli, as the case may be) should be absent from samples of finished drinking water taken at the treatment plant or, in many instances, throughout the distribution system. Unfortunately, the survey that was done did not yield adequate bases for comparing methods of laboratory quality control; nor was it possible to determine how corrective action is taken in the event that indicators are found in finished drinking water. Efforts being made by several organizations to standardize analytic procedures in water microbiology are certainly to be commended. Whatever the analytic procedures used, it seems clear that the ability of laboratory microbiology to contribute to the safety of drinking water depends less on how standards are written than on the dedication with which they are applied or enforced.

Topic E deals with the Treatment Methods used in producing finished drinking water. The emphasis in this case is on how various unit processes affect pathogens and indicator systems. However, much information on other aspects of some of the same treatments can be found in the reports of Project Area II: Advanced Treatment Technology. The variety and degree of treatment used in preparing drinking water should be, and usually are, determined by the quality of raw water that is available. Where the source is variable in quantity or quality, reservoir storage may be used to buffer some of the fluctuations. The primary function of the reservoir may be storage but considerable changes, for better or worse, can result from holding water in a reservoir. This depends on whether the reservoir is managed so as to minimize opportunities for contamination or growth of noxious organisms and to make use of the water's tendency for self-purification; at best, storage of water in a reservoir can serve as a treatment step, and is regarded as such in this report. Physical treatments, such as coagulation and flocculation or various versions of sand filtration, serve to remove suspended matter including many microbial cells. These treatments are especially important in removing protozoan cysts and metazoan eggs, as well as in eliminating suspended matter that might interfere with disinfection. Slow sand filtration, and often activated carbon treatment, have an important biological component. Activated carbon treatment is intended, primarily, to remove impurities that are dissolved, rather than suspended, in water. To the degree that the substances removed might have served as substrates for microbial growth, the growth becomes less likely to take place in the water, but more likely on the carbon surface. This will not necessarily produce a health hazard, but it can lead to disinfection problems and to a decrease in water palatability. The microflora in slow sand filters can effect important reductions in biodegradable dissolved substances especially in water pre-treated with ozone.

The ultimate defense against carry-over of pathogenic bacteria and viruses into finished water is, ordinarily, disinfection. If pathogens were unlikely to have been present in the raw water, disinfection may be done solely to suppress opportunistic organisms and to avoid technical problems during distribution of the water. This requires use of a disinfectant such as chlorine, a residual of which can be maintained throughout the distribution network. On the other hand, disinfection may be needed to kill large numbers of microorganisms, possibly including pathogens. Ozone is seen to be a major alternative to chlorine in this application; it is already well established as a primary drinking water disinfectant in many areas. Other disinfectants are also surveyed, and some of these may eventually capture a portion of the disinfection market. It is important to note that no disinfectant can make good water from bad, and that disinfection may fail if water has not first been treated in a manner appropriate to its original quality, so that the disinfectant has only to act upon reasonable numbers of microorganisms.

Topic F addresses the problem of maintaining finished water quality during Storage and Distribution. This represents a special challenge from both the standpoints of quality and safety. On the one hand, the quality of finished water at the treatment plant must be assumed to be the best that can be achieved with the means available, so that storage of finished water, for example, can maintain or degrade quality, but cannot improve it as in the case of raw water storage. On the other hand, the epidemiological record shows that cross-contamination and back-siphonage, by introducing raw sewage or otherwise polluted water into finished water in distribution, have been relatively important among causes of the rare outbreaks of disease associated with public water supplies. The most general problems are those of avoiding growth of organisms present in the finished water (for example, by maintaining an active level of chlorine in water thoughout the distribution network) and preventing contamination of the finished water from external sources (for example, by covering service reservoirs in which finished water is stored). The materials and the manner of construction of the facilities are critical at every stage. Water contact surfaces in reservoirs and in mains all too frequently include materials which may support microbial growth. The joints that have been well designed to exclude contaminants from without are sometimes found to present favorable conditions for microbial growth within the system. Older materials used in constructing water distribution systems all have disadvantages, including increasingly high costs of production and installation and, in some instances, exceedingly short service lives when in contact with the water of some communities. Newer materials and joint designs appear to offer important advantages, but the testing of these cannot always include all of the conditions to which they will be subjected in use at various places. Thus, unforeseen difficulties are always possible, even under what may be described as routine conditions.

Conditions in water distribution cannot always be counted on to remain routine. Perturbations of the system may occur through:

(1) necessary expansion of the distribution network because of growth of the community;
(2) use of large volumes of water to fight fires;
(3) natural or manmade disasters that disrupt the integrity of the network; and
(4) errors by users, beyond the direct control of a water authority, that result in back-contamination of the water in public distribution.

If appropriate designs and materials have been used in constructing a distribution system, water quality can be protected, in most instances, by properly organized maintenance and surveillance. However, regulation of users connected to the system, as well as the development of effective plans for dealing with emergencies, are important further aspects of operation.

## Recommendations Concerning Storage and Distribution

(1) Careful consideration must be given to the siting of service reservoirs.

(2) Dead ends in pipes must be avoided and disused apparati disconnected.

(3) Distribution and plumbing systems should consist of materials that will not support microbial growth. New products should be tested for their ability to support microbial growth before they are accepted or rejected.

(4) Control measures to prevent back-siphonage and cross-connections should be carefully maintained.

(5) Adequate disinfection procedures for the construction and repair of water mains are needed. Installers should be instructed to follow the installation codes exactly.

Topic G discusses Technological Problems in drinking water microbiology. A pervasive theme in drinking water microbiology is the avoidance, suppression, or destruction of microorganisms in water. As Topic G shows, some microorganisms have what might be regarded as a certain retaliatory capacity. Microorganisms have adapted to such a variety of aquatic environments outside of water systems that it is probably not surprising to find them so firmly entrenched in much of this manmade system as well. They may cause problems both in treatment and in distibution. Water pipes may be degraded by microbial action, either because the organisms were able to use the material of the pipe as substrate or because microbial metabolism caused minerals to be eroded from or deposited on the inner surfaces. Microbial cells themselves, and the slimes associated with some of them, are able to coat resins and filter media or the interiors of pipes so as to exert a direct adverse physical effect upon the function of the facility. It is not surprising that resin function would be extremely susceptible to microbial growth, given the fact that normal function of the resin depends upon intimate interaction between the resin surface and the water; however, it is also true that a thin microbial slime coat can significantly interfere with the hydraulic conductivity of a water main, even though the deposit obstructs very little of the inside of the pipe.

Another set of technological problems involves the storage of water aboard ships, and in containers for commercial distribution or for use in emergencies. In a way, one might assert that drinking water in these contexts needs to be even purer than that in public supplies, for these classes of stored water will ordinarily be used in exactly the condition that the consumer receives them. Problems associated with ships' water supplies are discussed in detail; some of these problems are shared with supplies of drinking water aboard all classes of public conveyances, but they may be more extreme with ships because longer periods of storage and greater volumes of water are involved, and because many opportunities exist for cross-contamination from wastewater, water from the ship's bilge, and wash water derived from the often-polluted water in which the ship floats. Water sealed in containers also requires great care, as to the initial quality of the water, the use of preservatives (if any), and the selection of a container. Obviously, those who must use packaged water in times of disaster will have no opportunity at that point to reject that which, on the basis of off-flavor, odor, or appearance, might be suspected of being toxic. On the other hand, those who regularly drink bottled water in their daily lives place their trust in the safety of the commercial product and are therefore vulnerable to any lapse on the part of the bottler or distributor.

This report necessarily emphasizes water treatment and control measures for routine use. However, it must be recognized that emergencies do arise and that plans for dealing with them should be made beforehand, as much as possible. Causes of emergencies, in what may be descending order of likelihood, include undetected deterioration in the physical apparatus, human error, power failures, adverse weather, willful mischief, earthquakes, and war. Both apparatus at the treatment plant and in the distribution network may be subject to deterioration or sudden malfunction. Human errors might include such events as construction machinery breaking water mains. Loss of electrical power could inactivate pumps, ozone generators, and vital control apparatus. Adverse weather can cause power failures; or extreme cold, floods, or windstorms may directly interfere with water treatment or distribution. Willful mischief would include any malicious act by which one or a few persons abused a water system in an effort to disrupt society. Earthquake prediction seems to be progressing, but is still not very useful for protecting water supplies. Finally, if war occurs, water systems may be disrupted incidentally to general bombardment, overtaxed through excessive water demand for firefighting, or directly targeted as a vehicle for biological warfare.

All communities are vulnerable to emergencies affecting their water distribution systems. However, there are potential differences, involving water sources and treatment, in susceptibility to emergencies. A community that has relatively low-quality water must use a complex treatment scheme and is vulnerable from that standpoint. On the other hand a community that derives very pure water from a deep aquifer will have no water at all if it loses its pumping capacity. Large water supply systems probably present more points of vulnerability than small systems, and communities that derive their water from distant sources are especially at risk.

If treatment is interrupted, but distribution is maintained, microbiologic safety can be achieved by drawing water from the tap and boiling it. Otherwise, any available water that does not contain acute toxicants may have to be boiled and used. Restoration of treatment and distribution services is likely to require extensive flushing and use of large quantities of chlorine to restore a system to normal; plans for such action should be made in advance, and key personnel should learn their tasks. Large communities, where great numbers of people might be unable to supply themselves with water in the event of a system stoppage, should consider storage of water for emergencies in moderate-sized containers at well-distributed and marked locations.

Industrialized nations in general share a relatively high level of public health, as measured by long life expectancies and low child mortalities, which is at least partly a tribute to the technical and institutional success of drinking water supply in these countries. Even private water supplies in these countries are often monitored on a limited basis, so that relatively few inhabitants use water has not been safety tested in some manner. It is, perhaps, noteworthy that the primary safety criteria applied, even to this day when many other aspects of drinking water safety are under scrutiny, are based upon microbiologic indicator systems. This is reasonable, for a great part of the public health gains that have been achieved in industrialized nations have resulted from reduced incidence of infectious diseases through sanitation. Hardly any aspect of drinking water microbiology would not be likely to benefit from further research, but it is important to note that presently available treatment techniques, monitoring methods, and other features of current drinking water supply practice are serving their purposes remarkably well. In a general sense, standards presently in effect must never be relaxed because the populations of industrialized nations, accustomed to a high level of sanitation, are likely to be quite vulnerable to any abrupt lapse in established drinking water practice.

Change is inevitable, however, and new classes of chemical contaminants are being indentified in wastewaters and in some raw waters from which drinking water must be produced. Aspects of these problems are discussed in Project Areas I and IV. Research is needed both on effective and feasible methods that will produce fewer undesirable disinfectant derivatives while serving the original purpose of disinfection, which is to kill as many microorganisms as possible in the water. The task of protecting source waters, from a microbiolgic standpoint, will be aided when more research results are available regarding detection methods for waterborne pathogens, as well as the probability of infection by ingesting different quantities of waterborne pathogens. Indicator systems that are intended to signal fecal or other microbiologic contamination of water might be further refined and standardized, but it seems likely that monitoring the adequacy of water treatment and disinfection could better be based on the development and application of a separate set of indicator systems. These, and indicator systems designed to detect recontamination of finished water in distribution, probably stand to be most improved by automation or modification to afford shorter readout times. In this age of dramatically improved international communication, it seems clear that more standardization of criteria for water quality and safety will ensue.

If primary disinfection procedures must be modified out of concern for interactions between the disinfectants and chemical contaminants of water, further research will be needed on the adequacy of alternative disinfectants. At the same time, it will be very important to determine and attempt to utilize the antimicrobial effects inherent in all of the other unit processes employed in water treatment. Research to aid in protecting the quality of finished water during storage and distribution will, assuredly, focus on the development of low-cost, durable materials that are inert to the microflora in the water, but there are also many other research needs in this area. To the degree that microbial growth is capable of creating technolgoical problems, which have been enumerated previously, it is important that research contribute more to the understanding of these microbiologic processes, for it may be that the organisms cannot be entirely suppressed, but only minimized. Finally, further research on the evaluation and maintenance of water quality in closed containers is still needed.

Many new concerns about drinking water safety have been raised in recent years. Because these generally relate to chemicals and may be associated with such dire effects as cancer, they have tended to overshadow the microbiology of drinking water. Under the circumstances, it seems fitting to close by pointing out that:

(1) the primary criteria of drinking water safety and quality are based upon microbiologic indicator systems; and

(2) in any major lapse in drinking water treatment and distribution practices, the most immediate consequences to consumer health are more likely to be caused by pathogenic microorganisms than by chemicals.

## GENERAL RECOMMENDATIONS

(1) Every public water supply should begin with the highest quality raw water that is available in quantities sufficient to meet the community's needs. Efforts to protect and improve the quality of source waters are important; both waste discharges and non-point sources of pollution should be considered in attempts to prevent or alleviate contamination. Where possible, water to be used for irrigation, or for industrial purposes other than food, drug, or cosmetic manufacture, should usually be drawn from less pure sources than those from which the public supply derives.

(2) Disinfection is necessary, but not always sufficient, to ensure the safety of drinking water from virtually any source.

(3) Complete treatment of drinking water, including at least coagulation and sedimentation with sand filtration or alternatively dual filtration

including effective slow sand filtration, followed in all cases by disinfection, is essential in all cases where source waters are unprotected and is highly desirable even with protected sources.

(4) Sound engineering practice is required to produce safe drinking water; microbiologic laboratory testing performed on a routine basis, according to standardized methods, and by properly trained and supervised staff, is an important basis for assessment of drinking water quality. Indicator systems for use in these tests may be selected for any one of the following purposes:

(i) to signal fecal contamination;
(ii) to detect any abnormal and probably undesirable conditions that may occur; or
(iii) to warn of the probable presence of specific pathogens.

Larger waterworks, at least, should develop microbiologic quality control procedures and baseline data for all stages of treatment from raw water through distribution. Prompt corrective action should be taken when norms are exceeded. At least one microbiology laboratory in each country should have the ability to detect waterborne pathogens, either for spot-checking or for investigating outbreaks, both from water samples and from clinical specimens. Results of tests for both indicators and pathogens should be shared on an international basis.

(5) Innovative indicator systems, capable of signaling fecal contamination, problems in treatment efficiency, loss of integrity of the distribution system, and perhaps the presence of pathogens, should continue to be sought. Rather than try to find a single indicator system that will serve all of these disparate functions at once, emphasis should be placed on individual systems offering convenience and economy that will allow more frequent testing.

(6) In addition to the well-established research on waterborne bacterial pathogens, considerably more research is needed concerning viruses and protozoa transmissible by drinking water, in the areas of the dose-dependence of peroral infectivity and pathogenicity, the detection of these agents in water, and their removal or destruction by water treatment and disinfection processes.

(7) Monitoring of raw water quality on the basis of appropriate indicator systems is desirable in all cases and essential in those instances where the usual purity of the raw water is such that less than complete treatment is used. At least one indicator system that is directly correlated with fecal contamination should be included; the choice of other indicator systems to signal other kinds of problems should be made on the basis of knowledge about local conditions.

(8) Materials of which water treatment and distribution facilities are constructed should be presented for chemical and biological stability. Testing methods, as well as results, should be shared internationally as much as possible; however, it is also best to test materials, before use in a given system, with the very water with which they will, in fact, be in contact.

(9) Finished water in distribution, in both public and semipublic systems, should be sampled at representative locations and tested microbiologically with a frequency that depends on the size of the population served. Private water supplies should be tested at least annually. In all instances, the presence of coliforms, thermo-tolerant coliforms, or E. coli in a 100-ml sample should be treated as unacceptable, or at the very least, undesirable.

(10) To minimize aftergrowth or other technological problems and to provide a means of determining whether cross-contamination has occurred, water in public supply distribution should wherever possible contain a measurable residual level of disinfectant (e.g., free chlorine) at all points.

(11) Inasmuch as distribution systems are a potential source of problems in all water supplies, every system should be under continuous surveillance. Where problems are identified,

they should either be eliminated by modification of the system or be mitigated by routine maintenance procedures.

(12) Procedures for the installation and repair of water mains should be established beforehand and applied diligently when needed. Plans for dealing with emergencies should be made and communicated, in advance, to those responsible for implementing them.

(13) Means are needed to control cross-connections, to ensure both that the consumer does not degrade publicly-supplied water to the detriment of his own health and that his use of the water does not cause contamination that threatens the health of others. Aspects of particular concern include water supply systems in buildings, attachment devices that use water, and point-of-use treatment units attached to the consumer's tap.

(14) More intensive research and epidemiologic surveys are needed to determine the true health effects of microbes and their products in finished drinking water. For this purpose, closer cooperation and communication are needed among practicing physicians and veterinarians, public health authorities, and water microbiologists. Any proposed change in treatment, distribution, or quality control practice should be evaluated from the standpoint of probable impact on public health, as far as possible, before implementation.

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# CHAPTER VI

## AREA IV

## HEALTH EFFECTS

## SUMMARY *

PROF. JOSEPH BORZELLECA, CHAIRMAN

Various methods of disinfection are successfully used to control water-borne diseases due to biological contaminants in water (viruses, bacteria). These methods of chemical control add chemical contaminants to the drinking water. For example, chloroform and carbon tetrachloride have been found as contaminants in the chlorine gas. Trihalomethanes may be formed by the interaction of chlorine with humic and/or fulvic acids. In addition. chemical contamination may arise from natural, agricultural, industrial or distribution sources. Acute or chronic exposures to these chemicals may result in adverse health effects that are immediate or delayed, reversible or irreversible. Since these contaminants rarely occur singly, chemical interactions (additives, synergistic, antagonistic) must be considered. The nature of the adverse health effects as a result of a single chemical, can usually be determined from properly designed and executed animal experiments. Human epidemiological studies may

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demonstrate the adverse health effects of complex mixtures. Potentially toxic agents may also be identified by the use of short term or in vitro tests. Other methods of identification of potentially toxic agents include chemical structural similarity with known toxicants.

Attempts should be made to reduce the number of potentially toxic chemical contaminants, but the microbiological quality of drinking water must not be compromised.

The charge to this group, to determine the safety of drinking water, is an enormous one. Saftey has become an issue because of the large number of chemical contaminants that have been identified. The Committee critically examined some of the problems and established a set of objectives (Table 1).

Three major classes of contaminants were identified as biological (viruses, bacteria, protozoa), chemical (organic, inorganic) and physical (particulates, radionuclides). The Committee addressed the chemical and physical contaminants. The biological contaminants were reviewed by Group III.

Identifying and listing chemical contaminants found in the drinking waters of the countries represented on the

## TABLE 1

Objectives:

1. To list, identify and provide data on concentration and location of contaminants.
2. To identify source of contaminants as "naturally present" or introduced as a result of disinfection.
3. To categorize contaminants into chemical groups.
4. To critically assess available pertinent animal data and epidemiological data.
5. To identify adverse health effects that could follow exposure to contaminants.
6. To prioritize chemical contaminants with respect to adverse health effects.
7. To address issues of chronic ingestion of low levels of contaminants.

Committee was a formidable task. A subcommittee was formed to collect the data and prepare the list. The following information was requested for each contaminant:

- proper identification;
- origin (naturally occurring, manmade or the result of treatment);
- concentration(s); and location(s).

The data were computerized and a final listing was prepared. A sample page appears as Figure 1. Data from 14 countries were submitted; 744 entries appear in the listings. Three lists were prepared. They are identical in content, but the order of appearance of the contaminants differs. The contaminants are listed in descending order of concentration; alphabetically; and alphabetically, by country. There are 7 columns to each list:

A. Compound

B. Location (LOC) at which sample was taken

C. Country of origin (France, Switzerland, German Federal Republic, The Netherlands, Denmark, Yugoslavia, Italy, Czechoslovakia, U.K., Norway, Luxembourg, Austria, Canada, U.S.A.)

D. Source of raw water (surface = river, storage reservoir, etc.)

| Compound: | LOC: | COUNTRY: | Source of Raw Water: | Treatment Method: | MAX CON: ( 100,000) | REF NUM: |
|---|---|---|---|---|---|---|
| Bromodichloromethane |  | Netherlands | Surface | Chlorination<br>Storage Reservoir | 20.0 | 149 |
| Dibromochloromethane |  | Netherlands | Surface | Filtration<br>Coagulation<br>Chlorination | 20.0 | 06 |
| Toluene |  | German Fed Rep |  | Filtration<br>Chlorination<br>Ozonation | 20.0 | 239 |
| Dibromochloromethane | TWT | Netherlands | Surface | Coagulation | 13.3 | 02 |
| Chloroform |  | Canada |  |  | 13.0 | 130 |
| Bromodichloromethane (Terminal) |  | United States |  |  | 11.0 | 140 |

Fig. 1. Computerized data - Drinking Water Pilot Study

| Compound: | LOC: | COUNTRY: | Source of Raw Water: | Treatment Method: | MAX CON: ( 100,000) | REF NUM: |
|---|---|---|---|---|---|---|
| Dichlorobenzene Isomers | | German Fed Rep | Surface | Filtration<br>Chlorination<br>Ozonation | 80.0 | 239 |
| Chloroform | | Netherlands | Surface | Filtration<br>Coagulation<br>Chlorination | 60.0 | 06 |
| Trichloroethane | | German Fed Rep | | Ozonation | 55.0 | 239 |
| Bromodichloromethane | | Netherlands | Surface | Filtration<br>Coagulation<br>Chlorination | 55.0 | 06 |
| Chloroform | | Netherlands | Surface | Chlorination | 54.0 | 149 |
| Benzo(a)pyrene | | Netherlands | | | 50.0 | 02 |
| Isodecane | | German Fed Rep | | Filtration<br>Chlorination<br>Ozonation | 50.0 | 239 |
| Chloroform (Terminal) | | United States | | | 45.0 | 140 |
| Fulvic Acid | | United Kingdom | | | 29.0 | 98 |
| Chloroform (Quenched) | | United States | | | 22.0 | 140 |

Fig. 1. Computerized data - Drinking Water Pilot Study

E. Treatment method (filtration, coagulation, chlorination, ozonation, mutimedia filtration, sand/dune infiltration, bank infiltration, aeration, active carbon, fluoridation, storage reservoir, other, no treatment)

F. Maximum concentration (ppb)

G. Reference number (see reference number directory)

These tables identified contaminants and provided data on their location and concentration.

The origin of the contaminants was also addressed; i.e., were the contaminants naturally occurring, man made, or the result of the treatment. The naturally occurring contaminants include organic (humus) and inorganic (geological or natural weathering); the man-made ones include atmospheric, industrial, agriculatural, land-fill, surface run-off and household. Contaminants formed as a result of treatment include trihalomethanes. Special attention was accorded the influence of treatment on chemical contamination of water. The term treatment includes "everything done to the water from the time it enters the reservoir, canal or pipe until it flows from the customers tap" (WHO). Some of these treatment modalities and their input are summarized in Figure 2.

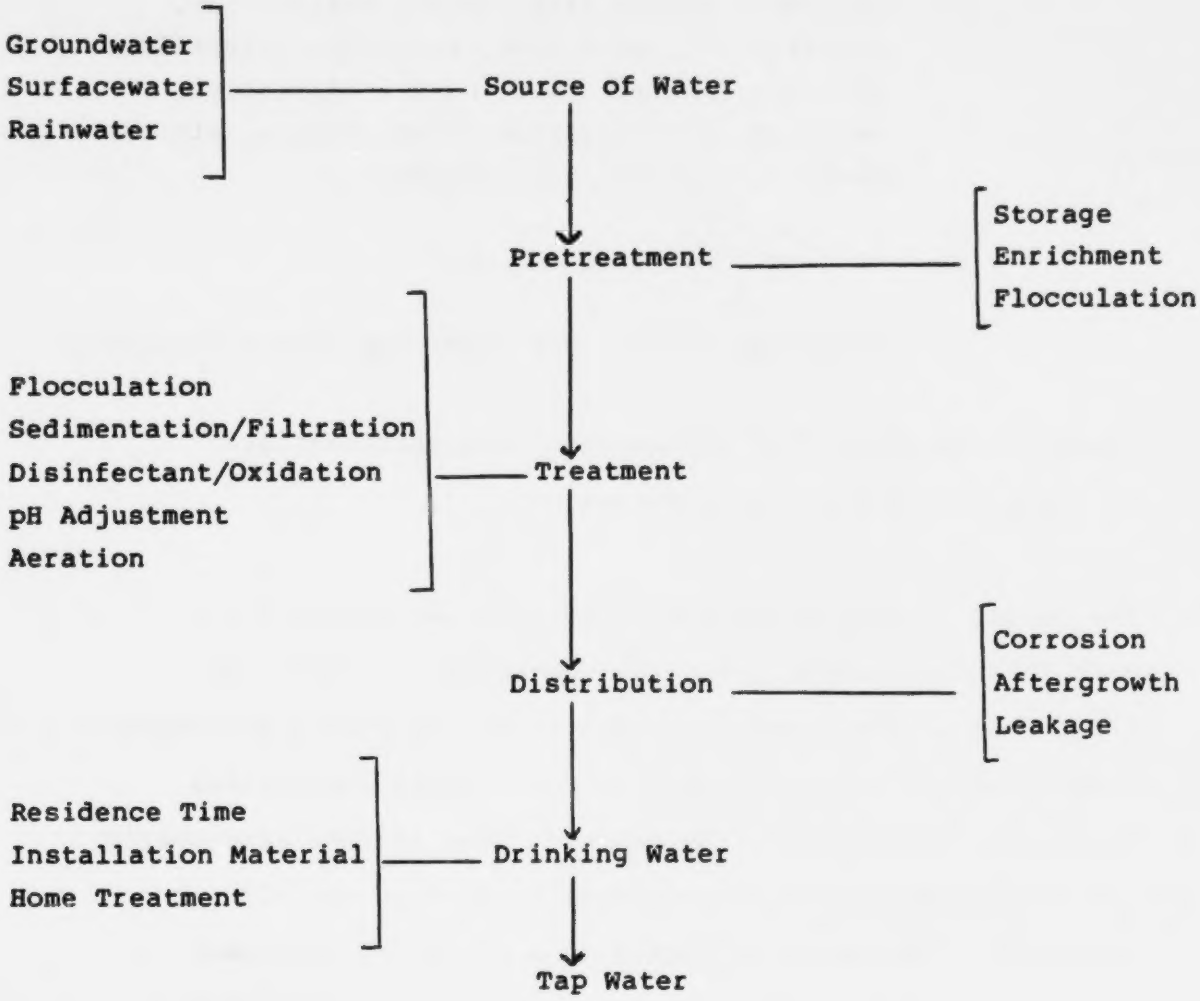
Groundwater
Surfacewater
Rainwater
Source of Water
Pretreatment
Storage
Enrichment
Flocculation
Flocculation
Sedimentation/Filtration
Disinfectant/Oxidation
pH Adjustment
Aeration
Treatment
Distribution
Corrosion
Aftergrowth
Leakage
Residence Time
Installation Material
Home Treatment
Drinking Water
Tap Water

Figure 2. Sources of Contamination

The raw water could contain a spectrum of chemicals, from simple ions in the solid to agricultural and industrial chemicals. During storage in reservoirs, atmospheric pollutants could enter the water and add to the chemicals present. The microorganisms present in the water are also involved in the formation of organic compounds. Some of these organics could adsorb onto clay and from flocs that settle out. During transport, materials from piping could leach out into the water.

The use of chemicals in the treatment train will add to the burden of chemicals in the water. For example, the use of $Al_2(SO_4)_3$ or $FeCl_3$ to develop flocs (which adsorb contaminants) will add to the anion and cation loads by increasing levels of sulphate, chloride and metals. Filtering aids, lime or sodium hydroxide to adjust pH, and softening agents will add chemicals. Since the chemicals used in water treatment are often technical grade, the impurities present are also a source of contamination.

Chlorine is probably still the least expensive and most effective disinfectant. Chlorine has been reported to interact with various constituents of water to form a variety of chlorinated and oxidized compounds. For example, chlorine will react with humic acids to form trihalomethanes; with

## TABLE 2

Selection Criteria:

1. Positive identification in drinking water
2. Distribution (frequency of observation)
3. Evidence of toxicity to animals or man
4. Chemical relationship to known toxic substances
5. Potential for contamination based on production figures
6. Listing in legislation (cited in regulations)
7. Organoleptic properties

## TABLE 3

## CLASSES OF AGENTS SELECTED FOR EVALUATION

Chemical Classes

1. Polynuclear aromatic hydrocarbons
2. Aromatic halogen compunds
3. Nitro compunds (organic, inorganic)
4. Esters
5. Aliphatic organo halogens
   - 5.1 methane derivatives
   - 5.2 ethane derivatives
   - 5.3 unsaturated hydrocarbon derivatives
6. Ethers
7. Cyclic aliphatic compounds
8. Halogenated phenols
9. Benzene and substituted benzenes
10. Humic materials
11. Inorganics (metals, non-metals)

Physical Class

1. Particulates

phenols to form chlorophenols. It has been suggested that when chlorine interacts with sewage over 50 chlorine-containing compounds with a molecular weight less than 1000 are formed. Treatment with chlorine dioxide may result in the formation of both oxidation products and halogenated compounds.

Contaminants contributed during distribution include leachates from piping (asbestos, metals, monomer), polycyclic aromatic hydrocarbons from bitumen (pitch) and corrosion products.

The committee then reviewed the list to determine what other compounds should be evaluated. Selection criteria were established (Table 2). Eleven chemical classes and 1 class of physical agents were identified (Table 3). Select members of each class were identified for further evaluation. The committee did not wish to repeat evaluations already conducted by other groups.

The primary concern of the Committee was the health effects of the chemical contaminants.

A number of factors should be considered in assessing the toxic hazards of chemical contaminants in drinking water. These include:

- exposure (concentration, route, time), toxicity in animals and man,
- chemical-biological interactions, and
- extrapolation of animal test data to man (Tardiff, 1976).

In the assessment of risk to human health, three types of data are important (Figure 3):

- physical and chemical properties,
- toxicological, and
- pharmacological data and epidemiological data.

The general outline for presentation of the data is presented in Table 4. The adequacy of the data would then be evaluated by the Committee and appropriate recommendations made.

Physical and chemical data were generally available. Acute and chronic toxicological data were often limited. Acute toxicity refers to single exposure where the response may

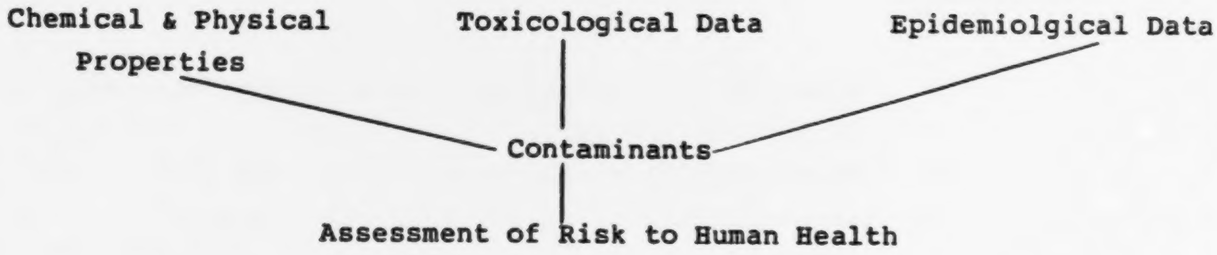
Chemical & Physical Properties
Toxicological Data
Epidemiolgical Data
Contaminants
Assessment of Risk to Human Health

Figure 3. Types of data required to assess risk to health

## Table 4

## GENERAL OUTLINE FOR DATA ON CHEMICAL CONTAMINANTS

I. Sources and Distribution of Contaminants

    A. Concentration Range of Contaminants

        1. Raw water
        2. Finished water
        3. Tap water

    B. Physical and Chemical Properties of Contaminants in Water

    C. Sources, Occurrences

        1. Production

    D. Estimated Total Exposure (body burden)

        1. Food
        2. Industrial exposure
        3. Accidental discharge into water
        4. Air

II. Pharmacological Data

    A. Absorption

    B. Storage, Distribution

    C. Biotransformation/pharmacokinetics

    D. Excretion

    E. Mechanism of Action

III. Toxicological Data

    A. Acute Effects

        1. Animal
        2. Human

    B. Chronic Effects (known or anticipated)

*1. Carcinogenicity
*2. Mutagenicity
*3. Teratogenicity
*4. Other toxic effects
*5. Interactions

*When applicable, should include data on:

1. Dose-response
2. Extrapolation
3. Margin of safety
4. Morbidity and mortality

C. Epidemiological Data
D. Especially Susceptible Segments of Population
E. Beneficial Effects; Adverse Effects

IV. Analytical Procedures (not essential)
A. Drinking Water
B. Biological Samples
C. Reliability of Data
D. Identification of New Contaminants

V. Research Needs (not essential)
A. Basic Mechanisms of Toxicity
B. Analytical Methodology
C. Epidemiology
D. Priorities

VI. Summary and Conclusions

be immediate or delayed. Chronic refers to multiple or repeated exposure. The response assumes many forms: cancer, mutations, birth defects, and other adverse health effects. Epidemiologic data, retrospective and prospective, were also very limited.

Short monographs were then prepared on the topics selected. These were critically reviewed and recommendations offered.

A number of critical issues were identified and addressed by the Committee. These included:

1. body burden of contaminants - assessment of total exposure involving food, air, water.
2. role of epidemiological studies in a water safety program. A workshop was held under the cochairmanship of Drs. Schneiderman and Biersteker (and this will appear as an appendix to our full report).
3. biological monitoring program. The use of either short term tests or combination whole animal and short term tests were considered. A workshop on short term testing was held (and the proceedings appear as an appendix to our full report).

A combination approach, a matrix, was proposed by Dr. Tardiff in 1976 (Figure 4). An alternative plan was recommended by Dr. Newell of the National Academy of Sciences. Water is first concentrated. A sample is then assayed using the Ames and *E. coli* tests. The concentrate is then administered by mouth to a series of mice at doses of 1, 3, 10 g/kg. Careful observations are made of the next 5 - 7 days.

Three (3) days after dosing, urine is collected from the mice and re-assayed in the Ames test. This will identify mutagenic metabolites that may have been formed. Five or seven days after dosing, the surviving mice are sacrificed and examined grossly. Bone marrow is taken and examined cytogentically.

These programs are for screening or monitoring purposes only.

A safety evaluation program (Figure 5) is more complex and should be considered only if a real need for these data has been established.

## CONCLUSIONS AND RECOMMENDATIONS RELATED TO CHEMICALS IN DRINKING WATER

1. In general, no adverse health effects have been observed from the consumption of drinking water which has been

## Matrix for Bio-Screen of Organic Concentrates from Tap Water

| Assay | Sample/City at 2 month Intervals | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Range Finding ($LD_{50}$ mouse) | X | | | | | |
| Mutagenesis (bacteria & yeast) | | X-f | | | X-f | |
| Mammalian Cell Transformation | | X-f | | | X-f | |
| In Vivo Carcinogen bio-assay (neonate rat) | | | X | | | ? |
| Teratogen Assay (rat) | | | | 4 | | ? |
| Chemical Characterization (GC/MS) | ? | ? | ? | ? | ? | ? |

Tardiff, 1976

Figure 4

## SAFETY EVALUATION PROGRAM

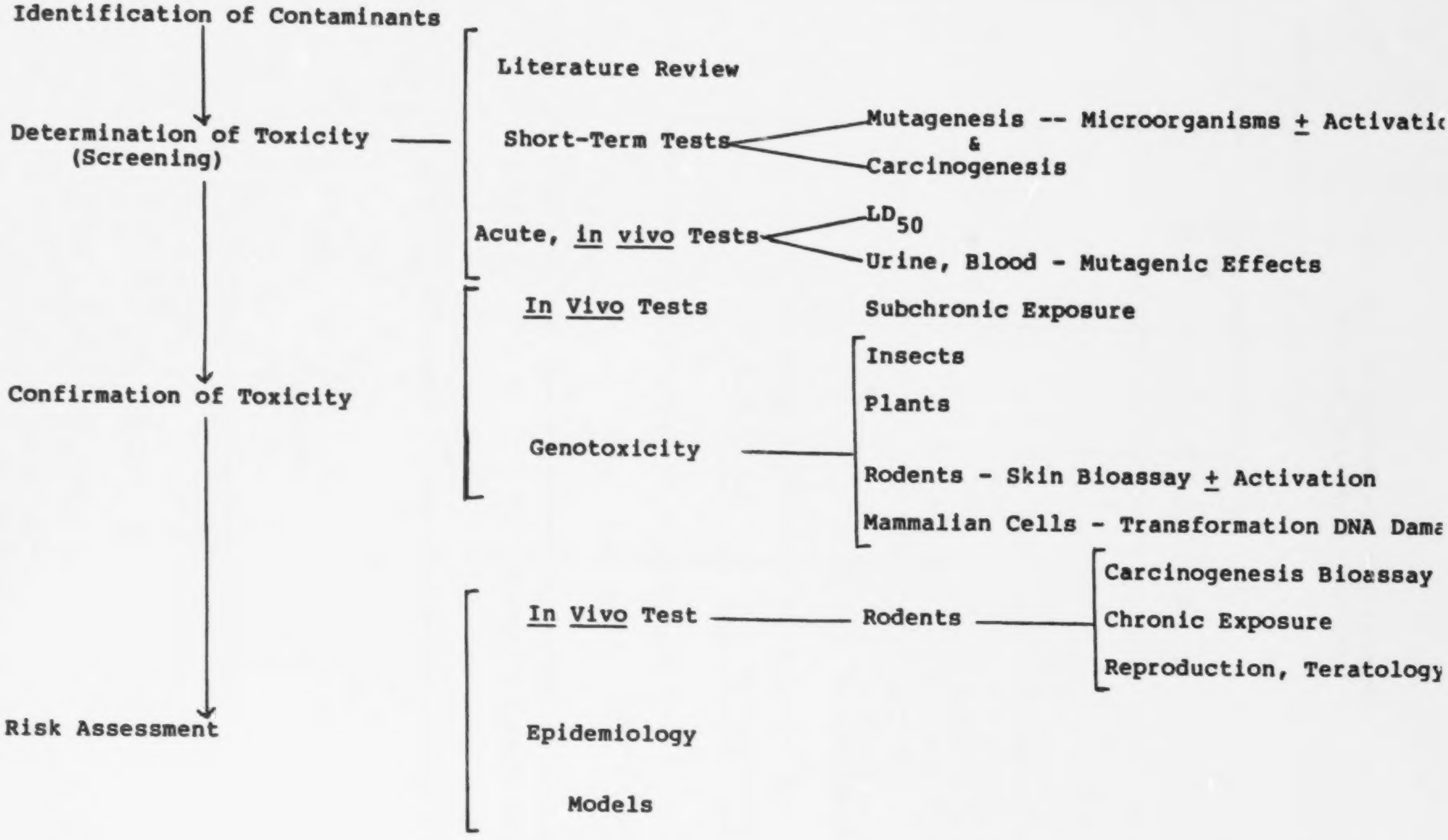
Identification of Contaminants
Determination of Toxicity (Screening)
Confirmation of Toxicity
Risk Assessment
Literature Review
Short-Term Tests
Mutagenesis -- Microorganisms ± Activati
&
Carcinogenesis
Acute, in vivo Tests
LD50
Urine, Blood - Mutagenic Effects
In Vivo Tests
Subchronic Exposure
Genotoxicity
Insects
Plants
Rodents - Skin Bioassay ± Activation
Mammalian Cells - Transformation DNA Dam
In Vivo Test
Rodents
Carcinogenesis Bioassay
Chronic Exposure
Reproduction, Teratology
Epidemiology
Models

Figure 5

generated in a controlled public water supply (i.e., adequate source protection, treatment methods and distribution system) and which met drinking water standards. Nevertheless, known contamination of drinking water from eutrophication processes in reservoirs, and by chemicals from some disinfection practices, industrial discharges, hazardous waste disposal, corrosion of piping and water softening remain sources of potential health hazard. Health risks have been associated with a failure to protect the source, to provide adequate treatment, or to ensure the integrity of the distribution system. Cases of acute intoxication represent a very small number of individuals in the last decade in the NATO countries.

2. Since present methods of disinfection are capable of controlling most microbiological contaminants, concern has been shifting from these to chemical contaminants.

3. Where experimental animal studies are used to predict human risks from longterm low level exposure to chemicals in drinking water, two basic uncertainties are ever present: one is the complexity and uncertainty of the extrapolation from experimental animals to humans,

and the other is the shape of the dose-response curve below the high-dose experimental range. There is evidence that one can predict, qualitatively and quantitatively, risks to humans from exposures to chemicals by the application of results from studies using experimental animals. However, in some cases (e.g., arsenic, benzene) such a correspondence does not exist.

4. In the study of long-term effects of low-level exposures, evidence of adverse health effects in groups of humans exposed at environmental or occupational levels are often quite reliable in establishing risks to the human population. However, it must be acknowledged that, within practical limits, epidemiology will not be able to confirm the small increases in disease incidence commonly predicted by animal experiments. Epidemiological studies should be encouraged, but only when they are expected to be of a sensitivity sufficient to detect the predicted effect or when they are clearly acknowledged to be hypothesis generating in intent. The most rigorous methods and standards of design and interpretation must be used.

5. When estimating hazards of chemicals to humans, it is essential to consider exposure from all sources

(air, food, water, occupational exposure, lifestyle, etc.) and also in which chemical state the pollutants are present. In general, drinking water is a minor source of total daily and lifetime exposure to most environmental chemicals.

6. Where risk of toxic effects is estimated for various levels of exposure, the acceptance of a particular level of risk is a socio-political judgement.

7. In order to make an accurate evaluation of the exposure to drinking water constituents, it is necessary to consider factors such as the volume of water consumed, the fluctuations with time of concentrations of chemicals in tap water, modification during beverage preparation, and the contribution made by drinking water used for culinary purposes. Many of these factors are difficult to evaluate, and it is recommended that studies be undertaken to define exposure more accurately.

8. Substantial concern has been raised about the nature and possible hazards of disinfection by-products. Research aimed at the elucidation of the chemical composition and toxicity of these by-products is strongly encouraged.

9. The treatment of water for potability often requires the use of chemicals. These should be used to maximize the removal of contaminants from the source water but without the addition of unnecessary amounts of chemicals and without compromising microbiological quality. Furthermore, these compounds added to water should be of high purity to avoid unnecessary, and possibly detrimental, contamination of the finished water. Similarly, storage and distribution materials should not adversely alter the quality of the water stored and conveyed.

10. A means for monitoring the toxic potential of the chemicals in tap water in a rapid and comprehensive manner should be sought. Studies aimed at the development of simple assay methods are strongly endorsed. Similarly, a flexible and reliable strategy for the application of such methods should be developed.

11. Information concerning the health effects of chemical contaminants is growing rapidly. Periodic review of these data is recommended.

12. The NATO/CCMS Master List of Organic Chemical Contaminants should be kept current. Participation by all NATO

countries is strongly encouraged. Study of the role of chemical constituents in potable water in the etiology and expression of human disease should concentrate on those instances where they may be factors in common diseases (for example, cardiovascular disease, cancer); should be considered a part of the overall strategy of disease investigations, and should deal with possibilities of benefit as well as harm.

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# CHAPTER VII

## AREA V

## REUSE OF WATER RESOURCES SUMMARY

MR. ALBERT GOODMAN, CHAIRMAN

Introduction. "Virgin" or previously unused water, where it exists at all, is insufficient to meet the demand for all uses. The demand can be met by re-using water which has already been used one or more times for some purpose. Direct reuse is the planned and deliberate reuse of treated wastewater for some beneficial purpose, such as irrigation, recreation, industry, ground water recharge and, occasionally, for human consumption. Indirect reuse occurs when wastewater is discharged into natural surface waters (or percolates into an aquifer) from which water supplies are drawn. The indirect reuse of water has occurred for centuries - communities have routinely drawn their water supplies from rivers into which upstream communities have discharged wastewater. However, direct reuse, particularly for human consumption, is a relatively new phenomenon.

Direct reuse of water for human consumption can be considered only if reliable technology for making wastewater safe to drink exists. Existing technology is capable of protecting consumers of reclaimed water from known dangers; however, the knowledge regarding the toxicity for the wide range of chemical and microbiological contaminants is limited. The acute toxicity of some chemicals is unknown, and more importantly, the chronic effects of long-term low-level exposure to many contaminants, and the synergistic effects of combinations of contaminants, have only begun to be studied.

The economics of treating wastewater for direct reuse are not generally attractive when compared to the cost of conventional sources of potable water. However, when conventional sources are limited or when water must be transported for long distances, reuse may be a competitive alternative. Given the uncertainties regarding the health effects associated with direct reuse, water should be reused first for industrial, agricultural and recreational purposes, and reused for potable purposes only as a last resort.

A questionaire was circulated to public agency officials in the member countries asking for information on reuse guidelines, the extent of direct reuse, the extent of indirect reuse, the proportion of reused water in indirect reuse situations, the bases used to determine the acceptable limit of reuse, the protection afforded to consumers where indirect reuse is practiced, the existence of studies of populations consuming indirectly reused water, the existence of studies of toxicity of concentrates from reused water, and the existence of any other studies on the health effects of reused water.

Replies to the questionnaire indicate that only the United States has issued partial guidelines specifically on the reuse of water. The countries of the European Community must comply with the "Directive on the Quality of Surface Waters Abstracted for Drinking Water" and the "Directive on the Quality of Water for Human Consumption," both of which establish quality standards and therefore possibly limit the extent of reuse.

Direct reuse of wastewater for potable purposes has been practiced only in emergencies in the United States, and then only on a limited scale. None of the other member countries reported instances of such direct reuse, although some limited experimental drinking water reuse was being carried out in South Africa.

Direct reuse of wastewater for non-potable purposes does occur extensively in the United States, the United Kingdom and the Federal Republic of Germany. The principal uses of reused water are for cooling, although reused water is sometimes used for quenching in steel mills. In the

Netherlands, direct reuse occurs regularly in the paper industry and in the sugar refining industry. In France, direct reuse of wastewater for industrial purposes does not occur to any great extent. The United States also reported the reuse of wastewater for recreational purposes (Lake Tahoe) and reuse of sewage effluents for the irrigation of golf courses and public parks.

Indirect reuse of both surface and ground waters occurs in all countries. In areas of Denmark, domestic sewage is applied to the ground where it percolates into ground waters. A 1961 report indicated that at low flows 3.5% to 18.5% of water consumed in the United states had been used previously. In the Paris region of France, 50% to 70% of the water has been reused. In the Netherlands and Western Germany, the Rhine and Meuse rivers are subjected to considerable reuse, and the Ruhr river may contain over 40% sewage effluent. Spain and Sweden both reported extensive reuse of the major surface water sources. The situation in the United Kingdom varies; extensive reuse of surface water sources occurs in England and Wales, but reuse is less significant in Northern Ireland and virtually non-existent in Scotland. In England and Wales, extremes of reuse are about 20% domestic sewage effluent and 36% industrial effluent (in different rivers). Many countries reported that reuse of major river sources has been occurring for long periods of time. Some rivers in the United Kingdom have been reused prior to 1900. The water supplies in the Paris region have undergone a marked deterioration over the last decade.

Guidelines for Water use. Most European countries have taken note of the recommendation in the WHO European Standards for Drinking Water, but none of these countries have imposed national standards. In the United States, guidelines for water use depend on the type of use or reuse. The United States has enforceable standards for drinking water quality, but not for other uses of water. The drinking water standards assume a high quality source water. In most other countries, reused water is judged on the estimated degree of reuse, the ammonia content, the chlorine demand, the amount of coagulant needed to effect treatment, the presence of substances affecting taste and odor, and the oxygen demand. More recently, total organic carbon content has been used as a measure of the extent of reuse.

Consumer Protection. In most cases, consumers of reused water are provided protection by the period of time between use and reuse, during which time microbiological and chemical purification takes place in the river itself. In many places, the interval between use and reuse is extended by storage in reservoirs or underground storage sites. The period of storage required varies from a few hours to several hundred days. River bank filtration and recharge of underground aquifers are processes used to extend the interval between use and reuse in other areas. Where storage cannot be provided, most countries have developed an alternate water source which can be used for blending when the extent of reuse exceeds the accepted value.

Another means for protecting consumers is to provide dilution of wastewater flows, even when river flows are at a minimum. Regulating reservoirs, which store flood flows for release during dry weather, have been constructed in France and the United Kingdom, while in Germany the Ruhr river and its tributaries are regulated to allow for sufficient dilution of wastewater flow at all times. An alternative dilution system being used in France and the United Kingdom involves pumping ground water into rivers to supplement existing flows, or, when river water quality is good, pumping river water into underground aquifers for storage until needed.

Monitoring of water quality is also used for protection of consumers from excessively reused water. Automatic monitoring stations are located on the Rhine river at the

Germany-Netherlands border, in France on the Seine and Oise rivers, and in the United Kingdom on several rivers. These stations measure pH, temperature, conductivity and dissolved oxygen as a general rule, and sometimes perform bioassays on fish. None of the automatic monitoring stations routinely measure organic chemicals, pending adaptation of automated gas chromatography or automated total organic carbon. All of the systems now in use are arranged to give warnings at manned remote control centers.

Treatment of waters containing waste effluents supplements routine monitoring, with the type of treatment varying in the different countries. Pre-oxidation, with chlorine in the United States, the Netherlands, the United Kingdom and parts of France, or with ozone in other parts of France and in Germany, preceeds conventional coagulation and filtering. Powdered activated carbon is used in 30% of all reuse situations in the United Kingdom, while granular activated carbon filters are used in France and Germany. Slow sand (biological) filters have been used for almost a century in the United Kingdom, and such filters are used by other countries as well. Infiltration galleries, making use of sand dunes and underground strata, are part of pre-treatment of reused waters of the Seine and the North Sea coast of the Netherlands.

Epidemiological studies of populations consuming reused water have been conducted in several countries. Results have varied, and no firm conclusions are yet available. One episode of acute illness (gastroenteritis) was traced to the Ruhr area of Germany when the water source contained 46% sewage effluent.

Extracts, prepared by chloroform extraction, reverse osmosis or ion-exchange have been fed to rats and mice for toxicological evaluation in France and the United States. In the United Kingdom, the Netherlands and the United States, reused waters have been assayed for bacterial mutagenicity by the Ames test.

Regulatory Control of Pollutant Discharges. Seven member countries, the Federal Republic of Germany, France, the Netherlands, Spain, Sweden, the United Kingdom and the United States responded to questionnaire inquiries on this topic.

In parallel with the enactment of the Federal Water Pollution Control Act Amendments of 1972 in the United States, legislation was introduced in the other member countries to maintain or upgrade the quality of surface waters. In the Federal Republic of Germany, the Federal Water Act of 1957, as amended in 1976, requires formal authorization of any usage of water which goes "beyond customary practice." In France, the Water Law of December 1964 establishes that all discharges are subject to authorization. In the Netherlands, the Pollution of Surface Waters Act of 1970 establishes that a license must be obtained for any water use that deviates from customary practice. Sweden relies on a National Franchise Board for Environmental Protection which has legal authority to grant discharge permits on a case by case basis. The various Public Health Acts in the United Kingdom were brought together in the Control of Pollution Act of 1974.

In the Federal Republic of Germany, the Federal Water Act addresses water quality control, the control of discharges, monitoring, protection of certain areas and the designation of water protection officers. It covers surface waters, groundwater and coastal waters. The Waste Water Treatment Tax Act of 1976 provides economic incentives to limit harmful discharges, and is levied according to the amount of certain pollutants which are discharged into waters. The Law on Washing Agents specifies the environmental compatibility of washing and cleaning agents, and requires that producers notify the Federal Environment Agency of the composition and formulas of their products. Several other federal laws contain provisions relating to waste discharges.

The Water Law in France distinguishes between discharges into public sewers and discharges directly to the environment. For discharges into public sewers, only piped stormwater is exempted. Discharges from industrial facilities are regulated on the basis of hazard, sanitary quality or nuisance characteristics. Discharges directly to the environment must be authorized, with the degree of "noxiousness" being the criterion applied. The threshold for "negligible noxiousness" may vary with local conditions, such as the water quality objectives of the receiving waters.

The Pollution of Surface Waters Act of the Netherlands prohibits the discharge of waste matter, pollutants and harmful substances into surface waters unless a license has first been obtained. The Act is based on the principle that the polluter pays. Levies are imposed, in terms of average daily discharge per inhabitant per day, for discharges of heavy metals or reducing substances, for example. Polluters may also be fined if they have taken inadequate control measures, and contributions are required from indirect dischargers.

The authority of Sweden's National Franchise Board extends over all discharges of pollutants, whether to the air, land, sea, ground water or surface water, and is not limited to pollution involving water. The Board consists of a chairman, a lawyer with experience as a judge, a technologist and a member with experience in industry or local government, depending on the matter at hand. The decisions of the Board regarding discharge premits have the strength of law. Fixed standards are avoided in favor of a system which evaluates discharges on a case-by-case basis.

Prior to the enactment of the Water Act 1973, discharge of wastewater in the United Kingdom was under the control of local catchment boards, river boards or other local authorities. Under the Act, industry is required to pay for the use of sewers for their discharges, but there is no provision for payment for direct discharges to rivers. Since the Act enables the attachment of strigent conditions to permit for direct discharges, it offers industrial dischargers the option of paying for sewer use or paying for such treatment as is necessary for direct discharges.

Early public health acts in the United Kingdom assigned responsibility for "wholesome" or potable drinking water to local medical authorities, water companies or water authorities. When the United Kingdom became signatory to the EEO Directive on the Quality of Surface Water for Abstraction for Drinking Water, assessment of quality became less subjective. Disinfection of sewage or sewage effluent is required only in regard to treatment plants serving hospitals dealing with infectious diseases.

In the United States, the Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500) began a comprehensive effort to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters". The goals set by this Act are to achieve swimmable, fishable waters wherever attainable by 1983, and to eliminate the discharge of pollutants into navigable waters by 1985. It is presumed in this legislation that ambient water quality will be achieved by compliance with effluent limits for pollution discharges. The Act, more recently called the "Clean Water Act" with subsequent amendments, includes a wide variety of provisions, among them:

> Section 303, which requires the promulgation of ambient water quality criteria for such uses of water as swimming, aquatic life, and public water supply intakes.
>
> Section 402, which establishes the National Pollutant Discharge Elimination System (NPDES), requiring all point source dischargers of pollutants to obtain NPDES permits.

A requirement that all industries meet stringent and comprehensive standards by 1983, using the best available control technology economically achievable (BAT).

Requirements that limitations be met for the "priority" pollutants by July 1984.

Requirements that limitations be met for the conventional pollutants (including, but limited to BOD, suspended solids, acidity, fecal coliform) be met by July 1984.

Requirements that limitations for other pollutant be controlled within three years following the promulgation of guidelines by EPA, but in any case no later than July 1987.

A requirement that all municipal wastewater treatment plants provide secondary treatment by July 1983.

Section 208, which established the Water Quality Management Plan, a process for charting water quality decision-making for a twenty-year period. The effect of a Section 208 plan on the abatement of point-source pollution will be felt through its role in setting the conditions for individual NPDES permits.

Percentage of Reuse. It must be assumed that an increasing degree of water reuse leads to a corresponding increase in health risk. Therefore, in order to protect consumers, the degree of reuse needs to be determined. In the United States, degree of reuse has been calculated on the basis of the proportion of wastewater-derived materials from upstream discharges found in surface water supplies. In the Federal Republic of Germany, chlorine consumption has been used as a parameter for characterizing the organic quality of reused water. In most European countries, attempts have been made to define the degree of reuse on a volumetric basis. Chloride concentrations have been used as indicators of the degree of reuse, but examples of chloride concentrations increasing during heavy rainfall are known, thus casting doubt on the reliability of this measurement. Various tracer techniques have also been tried, among them the use of potassium dichromate, lithium salts and radioactive substances. More recently, total organic carbon and total organic chlorine have been proposed as indicators of the degree of reuse. Unfortunately, the latter parameter has been known to reflect the degree of algal blooms rather than the degree of reuse, since chloride may be assimilated in the metabolism of the algae to produce an increase in organic chlorine compounds. Boron appears to be a useful tracer, in that there are very few natural sources, and borates are widely used in detergents.

Treatment Options. Treatment options for the reuse of wastewater are as numerous as the different uses of recycled water. This discussion is limited to two specific cases: indirect reuse through ground water recharge, and direct reuse for potable water production. In both cases, it has been assumed that the water to be reused is of municipal origin and has been subjected to classic primary and secondary biological treatment in addition to treatment to remove heavy metals.

Ground Water Recharge. The treatment before recharge outlined varies from none at all to a combination of processes which may include coagulation, flocculation, filtering, powdered or granular activated carbon, nitrification, denitrification and ozonation. The "no-treatment" option is considered only for a high quality effluent, in limited circumstances, and should be complemented by a fairly complex treatment when the water is withdrawn. Other options depend on the quality of the recharge water - amount of suspended matter, ammonia, color, taste, odor, iron and manganese.

Direct Reuse. Since direct reuse for drinking purposes has been practiced only rarely and on a small scale, general recommendations remain largely theoretical. A wide variety of treatment processes are available, and two general systems, a "semi-closed" circuit and a demineralization system, can be considered. In the former, water is recycled until the concentration of dissolved salts reaches limits fixed by potability norms. Water from another source (with lower concentration of dissolved salts) is combined with the recycled water, and when the salt concentration is low enough, the circuit is "re-closed".

Demineralization can be accomplished by reverse osmosis, electrodialysis, ion exchange or distillation. After demineralization, the quality of the water must be corrected to achieve potability. Partial remineralization and aeration are essential. It should be noted that a direct reuse plant cannot be designed *a priori*, but must be based on pilot studies.

In any situation involving the reuse of wastewater to produce drinking water, three basic problems must be considered:

- Water quality - technical and health aspects
- Psychological response
- Ecomonics.

*Health Aspects of Water Reuse*. Health risks from reused water may be due to either microbiological or chemical contaminants. The degree of risk is proportional to the degree of human exposure, so the most serious risk is that associated with reuse for potable purposes. Because the self-purication processes in natural water are highly efficient for removal of microbiological and biodegradable chemical contaminants, it is generally accepted that potential health risks of direct reuse are higher than those of indirect reuse unless adequate reliable treatment has been employed.

The microbiological contaminants of concern in wastewater are pathogenic bacteria (Salmonella and Shigella), viruses (polio, coxsackie, Echo, infectious hepatitis, etc.), and parasites (amoeba, giardia, schistosoma). Viruses are more resistant to inactivation by water and wastewater treatment processes than are coliform bacteria, and this fact, in addition to the difficulty in detecting viruses at low concentrations, make viruses among the most difficult problems associated with wastewater reuse. While studies of advanced wastewater treatment show that pathogens, including virus, can be removed, treatment for reuse should contain a multiple safety barrier when potable reuse is contemplated.

Disinfection by-products and the inadequacy of coliform standards for reuse applications are problems which must be solved before the microbiological quality of reused water can be assured.

Inorganic chemicals can usually be detected and removed by available technology. However, only a small fraction of the organic chemicals have been detected and quantified, and only a smaller fraction have been evaluated for health effects. From a practical point of view, it is impossible to screen all individual organic compounds for toxicity. Thus, either a data bank containing all available toxicity data will have to be assembled, or renovated wastewater will have to be assayed using test animals. Due to the diversity and complexity of problems associated with the health risk of organic contaminants in reclaimed water, a close coordination of research on an international basis is highly desirable.

Industrial Reuse. The water required for industrial purposes can be classified into five general categories: boiler feed water, process water, cooling water, service water and potable water. Boiler feed water must have low concentrations of organic substances and total dissolved solids, and for high pressure steam the requirements are more stringent. Process water requirements will vary with the process, but in general, the contaminants of concern are those which foul catalysts, end up in the final product, react with raw materials, or cause scaling and corrosion of equipment. Cooling water must be low in suspended solids, dissolved solids and organic chemicals. Service water (used for cleaning, flushing and cooling) must be low in organics and chlorides. Potable water is usually required to meet current drinking water regulations.

Industrial reuse system are either simple, where the renovated wastewater is used once and then treated or discharged, or sequential, where the same water may be used for several purposes before being renovated or discharged. The chemical and physical treatment processes for renovation include primary settling, chemical classification, filtration, activated carbon adsorption, ozonation, ammonia removal and demineralization. Biological treatment includes biological filters, activated sludge, stabilization ponds and disinfection.

Agricultural Reuse. Municipal waste water is preferred for agricultural reuse, but the effluent from some industries can also be suitable. Besides the irrigation of croplands and pasture, effluents can be used for irrigation of parks, golf courses, etc. The critical contaminants affecting soil properties are settleable solids, sodium and exchangeable cations. The critical contaminants (both beneficial and adverse) affecting plants are plant nutrients, dissolved solids, salinity, heavy metals and boron.

Pathogenic organisms in municipal waste water may contaminate crops, present a health hazard when the effluent is sprayed, and can introduce parasites into animals which feed on irrigated pasture land.

Public Acceptance of Renovated Waste Water. Studies conducted in the United States indicate that acceptance of reclaimed water depends on the particular use intended and the intimacy of contact. The closer the contact, the lower the acceptance rate. Approximately 50% of those surveyed would not accept reused water for drinking or cooking, but there are variations in response in different regions and on the bases of education, income and other demographic variables. The most significant factors were public knowledge and education. The results of these studies indicate that a "scaler" approach might be helpful - use of renovated water would start with passive recreational uses and gradually progress to more intimate contact uses.

Case Studies.

I. Porsuk River, Turkey. This surface water supply is polluted by discharges from a fertilizer factory, a sugar house, a slaughter house, and a municipality. The city of Eskisehir needs additional water resources for a potable water supply. None of the waste discharges to the river receive treatment, and the most serious problem is that of ammonia in the wastes from the fertilizer factory. Ammonia is oxidized to nitrite and nitrate in the river.

The solution: The waste discharges are treated by conventional primary and secondary treatment. Rather than attempt treatment of the fertilizer factory wastes, the ammonia-rich effluent is disposed of by land application as a fertilizer. During periods of no fertilizer requirement, the effluent is lagooned. The river water receives conventional water plant treatment at Eskisehir.

II. Ruhr Valley, Federal Republic of Germany. The Ruhr river is a major source of drinking water for the areas, but is heavily contaminated with industrial and municipal discharges.

The solution: The individual communities construct and operate sewer systems, while the "Ruhrverband" is responsible for treatment facilities. The river water is purified by instream aeration and by recharge basins and infiltration galleries. The recharge basins refine water to potable quality by mechanical and biochemical processes. Prior to recharge, filtration and cascade aeration may be employed.

III. Thames River, United Kingdom. Water for London is taken near the estuary, and there are many municipal and industrial discharges up river. Water is pumped into reservoirs for storage before use.

The solution: The extent of reuse is calculated on the basis of boron content of sewage effluent and abstracted water. Boron (from synthetic detergents) appears to be unaffected by sewage treatment, passage down river, or by water treatment. Average reuse is maintained at approximately 13%.

IV. United Kingdom. A severe drought occurred in 1975-76. In many cases, river flows were maintained only be effluent inputs. After the dry period, a heavy rainfall occurred. The effects of these occurrences on water quality were of concern.

Results: Surprisingly, water quality remained good during the drought period. Apparently, the low flows and high temperatures resulted in denitrification, increased biological activity, reduced phosphate and, combined with the clarity of the rivers, reduced coliform counts. Evidence of exchange taking place between obvious surface flow of some rivers, and the concealed, but not inconsiderable, flows in gravels of the river bed allowed quality changes to be less severe than had been expected. This possible effect should be taken into account when degree of reuse is being considered.

Water Resources Management. This report has described the present trends in water resources management; it has not in any way tried to establish a universal management system.

# PROTOCOL DEVELOPMENT: CRITERIA AND STANDARDS FOR POTABLE REUSE AND FEASIBLE ALTERNATIVES

F. A. BELL AND J. A. COTRUVO, U.S.A.

A repeated question for the last 20 to 30 years has been, "Since we treat wastewater to such high quality, why throw it away, why not put it to potable uses?" This question when joined to increasing problems of water shortage, provides a real atmosphere for considering the reuse of wastewater. However, at this time, methods have not been devised and accepted widely to determine the acceptability of reuse water for potable purposes. National standards for drinking water quality are based on the use of raw waters from the best source and are inadequate for wastewater. In addition, factors of time and dilution provide a degree of protection for existing water supplies against the acute threats of chemical spills, a protection which may not be present in potable reuse schemes. Consequently the development of potable reuse criteria and standards emerges as an important national objective. Further, elements of various federal legislation, including the Safe Drinking Water Act, provide for attention to the health implications involved in the reclamation, recycling, and reuse of wastewaters for drinking.

Development of actual criteria and standards for potable reuse involves the consideration of acceptable risks, economics and other practical considerations as well as the scientific and engineering aspects. Consequently such development is a policy determination in the final analysis. However, development of a basic protocol for answering the scientific and engineering questions is a scientific and technical matter. For this latter purpose, EPA called together the most expert, talented and knowledgeable people in the pertinent scientific and engineering disciplines to plan, present and participate in this workshop.

The purpose of the meeting was not to develop specific criteria and standards but to provide guidance with respect to approaches, problems, solutions and needed research for establishing a pathway to protocol development for potable reuse criteria and standards and for consideration of non-potable options. Approximately 110 people representing a wide range of scientific and technical expertise and coming from diverse institutional backgrounds, federal, state, and local governments, consulting, professional associations, academic, manufacturing, private and environmental organizations -- participated and assisted with the work of this meeting.

## Statement of Concerns

An analysis of the various perspectives and factors relating to potable reuse and feasible alternatives demonstrates several general areas of concern:

Divergent philosophies can provide a substantial area for debate whenever potable reuse is considered. One side which suggests a hierarchy of water use says, "Let's give priority attention to the cleanest sources, let's exhaust non-potable options before considering potable reuse. In fact let's give such attention to preventive public health that potable reuse will not be considered until all other options including conservation, dual water systems, etc. are exhausted."

Another philosophy sets forth definitional problems. It says, "Look, we already have reuse in many major cities through polluted surface water streams; so why don't we say so --why don't we just admit it and start defining potable reuse the same as indirect reuse from a river, for example". This approach goes on to make the point that current advanced wastewater treatment (AWT) technology already produces effluents which exceed national primary drinking water standards. The consequence of this approach would be to approve direct potable reuse quickly with the addition of a few monitoring and operation and maintenance requirements.

Other philosophical variations on water reuse have been articulated but possible pathways for solution must be charted through these sometimes opposing philosophies.

Economic and social considerations will always be important to decisions about potable reuse but should not necessarily affect the scientific and engineering aspects of protocol development for potable reuse criteria and standards. While various studies have shown the national need for potable reuse to be less than one percent, there are still limited areas where the need for potable reuse would be intense.

In such cases of intense economic need for potable reuse, non-potable options are often considered either too unwiedly or expensive to accomplish or development of new fresh water sources and/or conservation options are unacceptable. A series of institutional and legal blocks such as water rights law, may also act to prevent the utilization of options other than potable reuse or may negate reuse as a viable option.

A second strain of considerations have to do with the social acceptability of potable reuse. A variety of studies and papers have addressed this subject: these were summarized in one of the introductory papers to this meeting.

Public health protection in the application of planned direct reuse and in existing indirect reuse situations represented the keystone for meeting deliberations. Since many indirect reuse situations already exist and require no fresh decisions at this time, the meeting was principally focussed on problems relating to possible new potable reuse ventures including groundwater recharge and various engineering schemes for accomplishing potable reuse. Areas of concern in criteria and standards development are outlined as follows:

## Chemistry

A principal concern related to the definition of inorganic and organic chemicals present in the raw source wastewater and for assessing the impact on criteria and standards development from the known and unknown components. The limitations and potentials of analytical and monitoring technology to provide needed information including possible surrogate methods and conjunctive use of a series of measurements, requires exploration. Chemical removal perspectives regarding various treatment schemes must also be addressed. With particular reference to unknown organic fractions, the availability and/or potential development of acceptable concentration schemes to provide materials for toxicological testing ranks as a key interdisciplary matter with the toxicologist. Finally, the impact of water treatment chemicals in forming toxic by-products (such as chlorine) and possible uses of alternates should be considered.

## Toxicology

The broad scope of acute and chronic health effects as related to known chemicals in wastewater and their impact on criteria and standards development requires exploration. Means, including *in vivo*, *in vitro* and combination/surrogate testing, of defining the toxicity potential of unknown organic fractions ranks as a number one priority. Epidemiology aspects also should be considered.

## Microbiology

The potential health threat of the various microbiological factors - viruses, bacteria, parasites - through potable reuse requires examination. The potential impact of treatment technology in meeting microbiological objectives must be considered along with the potential for using alternate disinfectants to chlorine. The validity of traditional indicators and possible schemes for development of microbiological criteria and standards for potable reuse must be addressed.

## Engineering

Engineering deals with the various physical schemes (direct once through; direct repeated recycling; simulated indirect reuse, etc.) for processing wastewater for possible potable reuse: the strengths and weaknesses of these schemes and their potential impact on criteria and standards development need to be addressed. Monitoring and process control and means of assuring reliability of plant performance require examination. The role of source control to regulate wastewater quality should be considered. Finally, the important role of pilot plant testing for various approaches must be examined as a key factor in criteria and standards development.

## Groundwater Recharge

Feasible ways for accomplishing groundwater recharge (deep well injection; surface spreading and infiltration; the dedicated basin approach, etc.) require definition along with their potential impacts on contaminant transformations and on criteria and standards development. Source control, monitoring, and process control should be addressed. Finally, any unique strengths or weaknesses of groundwater recharge with respect to the development or implementation of potable reuse criteria and standards are very important.

## Non-Potable Options

Represent an important means by which public water supplies can expand their total availability of water for domestic use. The feasible non-potable options together with criteria for decision making regarding potable/non-potable options needs to be addressed. A review of health/aesthetic criteria and standards for non-potable options together with consideration of further need for governmental action is most important.

## KEY FINDINGS OF THE WORKSHOPS

The following findings represent the key ideas and approaches emanating from the six technical issues papers and work group deliberations:

### Toxicology

Prevention of toxic effects from inorganic, radiologic and particulate substances can generally be handled by setting Maximum Contaminant Levels (MCLs) and by application of appropriate treatment technology. However the control of effects from organic substances presents more serious problems. Where adequate information is available on specific organics of concern, additional MCLs should be set by EPA. With respect to the non-MCL and unknown organic fractions a two-fold approach is recommended:

1. Concentrate studies with mixed organics: concentrate studies should be performed on not only the proposed reuse water but also on a series of controls --unconcentrated distilled water and organics concentrated from a relatively pure ground water source and from a municipal system known to be subject to municipal, industrial and agricultural pollution. The organics in the water should be concentrated 1000-fold and the concentrate

should represent the organics originally present and not be subject to serious chemical or other transformations. Toxicity tests should be conducted for subchronic effects, chronic effects, teratogenicity, reproduction, mutagenicity and immune system effects. Animal tests would be conducted by oral ingestion or gavage.

Results of the concentrate studies would provide the responsible governmental offices with an important segment of basic data for the acceptance or rejection of waters proposed for potable reuse or to require the provision of additional treatment prior to the retesting.

2. A second set of basic data would be provided by epidemiologic studies. This data should be integrated with toxicologic data wherever possible during decision-making processes.

The highest research and development priority was assigned to the provision of a representative organic concentrate for use in toxicological testing. The technique would have to be capable of concentrating thousands of gallons per day in order to provide enough material for the toxicology tests.

## Chemistry

Specific analytical methods exist for 114 specific organic priority pollutants and for other designated organic contaminants in drinking water. Careful systems of analytical quality control have been established for these contaminant analyses. However, many more specific organic contaminants remain without systematic methodology or quality control procedures.

The available chemical data base for reuse waters remains sparse and is not well documented. Information about non-volatile compounds is almost non-existent and many other organic compounds have been identified but not adequately quantitated. Major effort should be made to examine the unknown or inadequately identified organic fractions including broad spectrum analytical protocols and liquid chromatographic screening methods for non-volatile pollutants. The data base requires development and evaluation with respect to variability in source water concentrations, treatment process removal efficiencies and concentrations delivered to the consumer. Monitoring and computer access of the data base needs to be developed.

Non-specific organic analyses can be defined in terms of specific goals -- as surrogate parameters; as aides in unit process design; for monitoring unit processes; and for plant operational control. Currently no surrogate parameters can be suggested as a substitute for specific organic constituents of health concern but the total organic halogens method appears to hold the most promise. However, in the next ten years, non-specific procedures in conjunction with chromatographic profiles will need to be used for operational monitoring and control. Specific analyses would be conducted as a part of the basic chemical characterization or to check excursions in the non-specific data.

In terms of preparing organic concentrates, there is currently no single procedure that is capable of concentrating all of the organics for optimum toxicity testing. A system to remove and concentrate different organic groups by varying techniques was considered so that a representative sample could be made available to the toxicologist. A scheme for development and evaluation is suggested as follows:

- Isolate volatiles - use purge and trap - analyze and reconstitute
- Isolate non-polar and low molecular weight organics - use XAD-2 resin
- Isolate humics and polars - use XAD-8 or reverse osmosis
- Isolate humics and others - use reverse osmosis
- Isolate intermediate molecular weight range - methods need development.

Since a number of complexing factors such as artifacts, concentrate stability, organic-inorganic interface, overlap and the like, may be present, these approaches should be carefully evaluated in parallel and in series.

Basic information about inorganic chemicals in reuse water is more complete than for organics and a monitoring strategy for inorganic chemicals could be developed which would meet public health objectives. A mathematical analysis of repeated reuse recycling demonstrates that an infinite concentration for some unknown constitutent would not occur but that such a buildup would be subject to a steady state situation depending principally on the chemical input during each recycle, the percent removed in treatment and the degree (percent) of recycle.

## Microbiology

Proposals for direct potable reuse require a complete reevaluation of the means for biological control. There should be no detectable pathogenic agents in potable reuse water. Potable reuse requires stricter microbiological standards than the current national coliform MCLs but specific criteria for viruses, protozoa, helminths and some bacteria are impracticable because of varying source water densities and because of inadequacies in their detection and enumeration methods.

Available treatment technology appears to be capable of meeting any microbiological requirements but this does not remove the need for analytical confirmatory data nor the need to insure operational integrity of treatment systems. Reliable monitoring must be available and vigorously used.

Research recommendations include developing better information on disinfection, developing or improving analytical methods for viruses, protozoa, helminths and some bacteria in water, better definition of microbiological characteristics of raw wastewaters and to other elements which would support a satisfactory program for implementing potable reuse.

## Engineering

Areas considered in workshop deliberations included: quality of source; storage prior to treatment; specification of treatment processes and design criteria; process redundancy requirements; parameters affecting plant process control and operation; types and frequencies of sampling and monitoring for plant control; storage of treated water prior to use (recharge or surface reservoir); operation and maintenance criteria.

In considering the various available treatment schemes and approaches, it was felt that treatment technology does not appear to be a limiting factor and that maximum flexibility should be allowed in treatment schemes and designs so that the most cost effective approaches can be implemented which will meet health requirements, including fail-safe operation.

One set of standards should be applied to all drinking waters regardless of source. However, because present national drinking water standards are incomplete for potable reuse waters the expanded potable reuse criteria should include:

- monitoring of source quality, the frequency to vary with source quality.
- the setting of limiting concentrations, providing for acceptance or rejection of the water at various points in the treatment process to be determined on a case-by-case basis.
- provision for pilot plant studies to determine treatment and reliability requirements prior to plant design.

Storage of treatment plant influent can be advantageous for flow equalization, blending, plant reliability, spill mitigation or for other reasons. Protected storage of plant effluent can be helpful in providing lead time for monitoring and controlled diversion in the event of plant breakdown.

Operating and maintenance criteria are critical. Operation and maintenance and operator training manuals should be provided prior to plant start-up. Separate operator certification programs for a new class of potable reuse plant operators should be considered along with specific minimum qualifications for plant operators and supervisory personnel.

Thorough characterization of potential source waters for potable reuse was a major research recommendation involving:

- Source waters for evaluation should be selected from water short areas and priority attention should be given to imminent need locations.
- The characterization of source waters should be accomplished by using the limits of measurement technology as contrasted to measuring only drinking water MCLs and the listed priority pollutants.

- Multiple samplings should be performed to establish frequency of occurrence variability and calculated ranges over time for the various contaminants.

## Groundwater Recharge

Important benefits can be obtained by groundwater recharge. In addition to providing an economical means of storage with reduced evapotranspiration, subsurface passage removes some contaminants and retards in the movement of others, by means of filtration, biodegradation, volatilization, sorption, chemical precipitation, and ion exchange. Its use as part of a scheme to produce potable reuse water is encouraged.

With respect to the transport and transformation of contaminants in the subsurface environment, the following table summarizes the current state-of-knowledge with respect to the ability to predict impacts of groundwater recharge projects in such a way as to protect the resource for future use. This table obviously pinpoints organic and virus aspects as requiring priority research attention.

| Contaminant Class | Adequate Knowledge |  |
|---|---|---|
|  | Yes | No |
| Major cations and anions | X |  |
| Particulates | X |  |
| Nutrients (N&P) | X |  |
| Metals | (X) |  |
| Organics |  | (X) |
| Microbiological pathogens |  |  |
| bacteria and protozoa | (X) |  |
| viruses |  | (X) |

(The enclosing parentheses indicate that the categorization is especially subject to uncertainity.)

A combination of pre-recharge treatment and natural groundwater basin treatment can be used to minimize the need for treatment after extraction. Various treatment-recharge-treatment schemes are possible especially in a dedicated basin mode, but any scheme involving the application of waters containing certain classes of contaminants, the behavior of which in the subsurface environment is not adequately understood, should be tried only for research and demonstration purposes. All ground water recharge projects must be adequately monitored to confirm performance within appropriate design criteria and standards.

## Non-Potable Options

In the United States there are now more than 500 successful wastewater reuse projects utilizing non-potable options: such options are the preferred method of reuse and should be considered in the decision-making process before the potable reuse option. However, a variety of steps need to be taken before non-potable options can be given maximum utilization:

- Non-potable options should be considered as a part of the overall water resource in terms of planning and implementing major projects.
- Water reuse is included in the legislation, regulations and programs of several federal agencies: a better coordination and focus should be provided in the federal government.
- Industrial recycling has perhaps the greatest volume potential for reuse and should be encouraged through federal support of engineering studies regarding optimum water recycling within each of the major water using industries.
- Consistent and comprehensive national public health guidance should be provided for the various categories of non-potable use.

- A manual of current practice should be developed based upon existing experience regarding the design, operation and maintenance of reuse systems.

- A comprehensive informational guide on the economics and financing of reuse systems should be prepared and disseminated.

# KEY MEETING CONCLUSIONS AND RECOMMENDATIONS

Based on the findings of the various workshops, and the ideas and approaches advanced by the various speakers, panelists and other participants, the key meeting conclusions and recommendations are summarized as follows:

1. One Set of Drinking Water Standards.

   Since many surface waters are indirectly polluted with wastewater a single set of standards should be developed for application to all waters regardless of source. However, it was recognized that present national drinking water standards are incomplete for potable reuse, so that decision-making for potable reuse required additional research and investigation. Supplementary criteria are also needed for monitoring operational reliability and limiting concentrations for determining acceptance/rejection at various treatment points.

2. Characterization of Potential Reuse Source Waters.

   Since the data base is sparse, a thorough characterization of potential source waters, giving priority attention to imminent-need areas, for chemical and microbiological constitutents should be accomplished. The characterizations using all available analytical methodology as contrasted to measuring only priority pollutants and the like, should be performed as multiple samplings to establish frequency of occurrence, variability and calculated ranges over time for the various contaminants.

3. Unknown Organic Chemical Components.

A substantial portion of the organic content of wastewaters is either entirely unknown or inadequately quantitated. Information about non-volatile compounds is almost non-existent. Major effort should be made to examine the unknown or inadequately identified organic fractions, including monitoring broad spectrum analytical protocols, liquid chromatographic screening methods for non-volatile pollutants and development of a data base which can be readily accessed.

4. Toxicology Concentrate Studies.

With respect to delineating the unknown chemical components and the assemblage of a satisfactory data base, it was felt that this may prove to be the work of more than one lifetime: toxicology/concentrate studies may prove to be the logical tool for decision-making instead of complete chemical analyses and synergistic studies. Specifically, a 1000-fold mixed organic concentrate from the potential reuse water, along with three controls would be used for comprehensive toxicological testing. However, no single concentration procedure is capable of concentrating all of the organics; several schemes along with a potential list of complexing factors are suggested as priority items for investigation and evaluation. This area obviously is one that should receive continuing attention from toxicologists, chemists, and decision-makers.

5. Microbiological Requirements.

Current treatment technology appears to be capable of meeting any microbiological requirements but this does not remove the need for analytical confirmatory data nor the need to insure operational integrity of treatment systems. Any train of treatment elements, selected to meet microbiological requirements on a case-by-case basis, should be backed-up by reliable monitoring, using available methodology, for the key microbiological factors and this monitoring should be rigorously applied. There should be no detectable pathogenic agents in the potable reuse water.

6. Groundwater Recharge.

Important benefits, including storage, reduction of contaminants and others can be obtained by groundwater recharge and its use as part of a potable reuse scheme is encouraged. Various treatment-recharge-treatment schemes are possible, especially in a dedicated basin mode, but any steps which might result in increased contamination of the groundwater should be tried only for research and demonstration purposes.

7. Non-Potable Reuse Options.

In the decision-making process, non-potable options should be considered ahead of potable reuse and should be factored into overall water resource planning and implementation programs. A strengthened federal focus needs to be provided for water reuse activities and consistent and comprehensive national public health guidance should be developed for the various categories of non-potable reuse.

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# CHAPTER VIII

# AREA VI

# GROUND WATER CONSIDERATIONS

## SUMMARY

Dr. HORST KUSSMAUL, CHAIRMAN

Groundwater has many advantages over surface waters as a source of supply, such as normally consistent good quality, local availability, low treatment cost, and in some areas, the absence of a need for disinfection. Groundwater is, therefore, the main source of water supply in many NATO countries (see Table 1.2). The increasing rate of ground water abstraction and the spread of urbanization have resulted in a reduction of the quantity and quality of the available ground water. Artificial recharge is often used to overcome these problems in combination with soil protection and optimization of ground water use.

Ground water can become polluted in many ways. Although many instances of contamination are already known, their occurrence is likely to increase in the future because it often takes years before contaminated ground water reaches a well. Since the volume of waste materials is still growing, a number of sources of ground water contamination are of interest; these are considered below.

Disposal of domestic and municipal wastes, such as the discharge of more or less treated sewage effluent, leaky sewers, leachates from solid waste disposal sites, and disposal of municipal sludge to landfill sites, constitute major causes of ground water contamination. Also, the application of de-icing salts on road surfaces results in unacceptable contamination problems. Another main source is the disposal of industrial wastes. Large amounts of solid industrial wastes are disposed of within landfills. Impoundments containing liquid industrial wastes are also important. Disposal of liquid waste by means of wells is relatively cheap, but hazardous and therefore, limited by legal constraints. Furthermore, abandoned or unplugged wells may form permanent conduits for fluids to move downwards. Many thousands of such abandoned wells, boreholes and shafts exist in the heavily populated regions of the world.

Accidental spillage from a variety of sources may contribute a further serious hazard to ground water quality; e.g., leaks from gasoline service stations or fuel oil storage tanks. Other problems have been related to acid mine drainage, salt water coming through abandoned oil and gas wells, agricultural activities such as disposal of effluents from animal rearing complexes, and instrusion of sea water in coastal areas.

The major source of ground water recharge is rainfall infiltration through the overlying soil zone, with smaller contributions from induced recharge (from surface water bodies) and from artificial recharge. In all instances, the percolation of the water through the unsaturated zone changes its chemical composition. In fact, the chemical composition of the water is constantly in a dynamic state to maintain a physicochemical equilibrium with its environment. These interactions typically include:

a) dissolution processes, which tend to increase the ionic content of ground water,

b) chemical and physical phenomena, which result, for example, in ion exchange reactions and adsorption, as well as

c) biological activity, commonly resulting in the reduction of sulfates to sulfides and in nitrification or denitrification.

Numerous models of pollution transport in porous media, and mass transport in the unsaturated and saturated zones, have been developed. However, many of the mechanisms controlling pollution movement through aquifers are not yet sufficiently understood to allow their inclusion in a mathematical model. In addition, the transfer of laboratory scale models to full scale application often creates serious problems. Thus, a great deal more work is needed in order to accurately model and, hence, understand the changes occurring in water quality during underground travel.

In many countries, particularly in densely populated areas, the growth in drinking water consumption outstrips the growth in supply. In order to increase ground water resources, artificial recharge is of considerable importance in some countries. The essence of this technique lies both in the use of additional storage and the natural chemical, physical, and biological cleaning properties of the soil and subsoil for surface waters. Other advantages of artificia recharge include prevention of the intrusion of saline or otherwise polluted water into the ground water supply.

Artificial ground water recharge may be accomplished by introducing surface water in open pits, lagoons, or trenches into unconfined aquifers, or by vertical injection wells. This latter technique is especially useful with partly or completely confined acquifers. Artificial recharge may also be induced directly through a river bank.

Compared with the other methods of artificial recharge, bank infiltration has the disadvantage that it cannot be stopped in case of an accident involving hazardous substances in the surface water. However, it does offer the great advantage of low cost and of relatively small required area, which may be of particular importance in highly developed or otherwise congested areas.

For the effective protection of ground water the following theoretical aspects should be considered:

a) the definition of possible sources of pollution in terms of type and quality,

b) the classification of ground water systems with regard to their vulnerability to contamination,

c) the coordination of ground water development, waste disposal practices, and land use planning, and

d) the implementation of remedial measures to protect ground water resources.

Good ground water protection is provided by an undamaged, biologically active, overlying soil zone. A widely used approach for protecting ground water is the establishment of control zones in which possible hazardous actions are strictly regulated, especially to protect the ground water used by public water supplies in highly developed areas. The main criterion in establishing such zones is the residence time of water in the subsoil. A further important approach to the protection of ground water is the development of guidelines for dealing with pollution incidents, designed to prevent the entry of pollutants into the ground water.

Technical actions for the protection of ground water require a legal basis, however, and the extent of legal measures differ considerably in the different countries. In most countries, ground water use has to be permitted by public authorities. Further, many countries have laws regulate the discharge of substances which are able to pollute ground water. These concern solid waste disposal as well as the quality of waste water allowed to discharge. The delineation of water protection areas is not yet established, by law, in many countries, while other countries have enacted a variety of special laws (sewage disposal, disposal of oil waste, discharge of detergents, etc.) to support the protection of ground water.

## Conclusions

Ground water forms an important drinking water source in all NATO countries. In some areas, there already exists marked contamination of this source. Our prime concern for the future should be to retain ground water quality and prevent any action which may lead to the deterioration of natural good quality ground water.

Contamination has already occured in certain areas, and it may take periods of up to several decades to correct.

In order to achieve this, we need to know more about:

a) the pathways of natural recharge of aquifers,

b) the persistence , or attenuation, of chemical and biological pollutants in the unsaturated zones of aquifers,

c) the persistence, or attenuation, of pollutants in the saturated zones of aquifers, and

d) the natural distribution of chemical and biological constituents of ground water.

A suitable data collection system is necessary to monitor ground water quantity and its possible changes with time.

In some NATO countries, artificial recharge is important and techniques should be continuously improved to help in optimizing ground water development.

Recommendations For Future Research

Studies should be conducted on the natural variations in ground water quality and how these depend upon:

a) the input,

b) the groundwater flow,

c) the interactions between groundwater and rock matrix,

d) the influence of microbes,

e) the movement of individual organic and inorganic constituents of ground water,

f) the effects of flow through saturated zones on degradable and water-soluble substances,

g) the adsorption capacity and other properties of strata relevant to persistent chemical substances,

h) the changes in the constituents of ground water flowing through different rock types by the use of laboratory simulations,

i) the affects of biological and chemical clog of aquifers,

j) the residence and passage time of bacteria and viruses in ground water to achieve remo and/or disinfection, and

k) the potential impact of urban, industrial, and recreational activities on ground water development.

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# CHAPTER IX

# APPENDIX

# NORTH ATLANTIC TREATY ORGANIZATION/COMMITTEE ON THE CHALLENGES OF MODERN SOCIETY

The Committee on the Challenges of Modern Society (CCMS) was created in 1969, the same year the North Atlantic Treaty Organization (NATO) celebrated its twentieth anniversary.

Meeting in Washington in a commemorative session on April 10, 1969, the NATO Foreign Ministers heard President Nixon describe the Alliance as it entered its third decade. It was, he said "by its nature....more than a military alliance and the time has come to turn a part of our attention to those non-military areas in which we could benefit from increased collaboration."

These remarks introduced a United States proposal to create a Committee on the Challenges of Modern Society. This committee would explore ways in which the experience and resources of the Western nations could most effectively be used to improve the quality of life. This would be NATO's third dimension--a social dimension that would join a strong military dimension and a profound political dimension.

The United States proposal drew on Article II of the 1949 North Atlantic Treaty through which NATO members had agreed to contribute to peaceful and friendly international relations by promoting conditions of stability and well-being. The American proposal also expanded on the "Three Wise Men's" report of 1956 in which Foreign Ministers Lange (Norway), Martino (Italy), and Pearson (Canada) had called for greater non-military scientific and technological cooperation within the Alliance. The first result of this report was the establishment of the NATO Science Committee in 1958; 11 years later, the Committee on the Challenges of Modern Society followed in its path.

Acting on the Washington Communique of April 11, 1969, Permanent Representatives to the North Atlantic Council formed a preparatory committee to explore the best way of pursuing NATO's social dimension. Based on the Committee's report, the Council established CCMS on November 5, 1969. The first committee meeting was held at NATO Headquarters in Brussels, December 8-9, 1969.

At that meeting, the United States, Belgium, and Canada proposed the first five CCMS pilot studies. The United States representative, Dr. Daniel Moynihan, stressed that the time had come for the Allies to learn to cope with situations which were, to a greater or lesser degree, "recurrent, predictable, manageable, and avoidable." His words have accurately predicted the evolution of the CCMS work program, demonstrated by the strength of the Allies" technological and scientific resources when applied in common to a specific problem. Today there are more than 30 CCMS pilot studies completed or in progress.

At that first plenary, Dr. Moynihan and Candian NATO Ambassador Campbell expressed the hope that CCMS would become a marketplace of ideas and techniques from each member country. Over the years, this hope has been fulfilled and the marketplace has expanded through the Environmental Round Table, the pilot studies themselves, the CCMS Fellowship Program, and several major international symposia.

The remarkable success of CCMS stems from the commitment of the Allies to respond on both national and international levels to the growing awareness of the magnitude of environmental problems. It undescores the vitality of the Allies' national political structures and the high degree of cooperation that they have come to expect from each other. It also demonstrates how the democratic processes in the NATO countries can be effective in translating the concerns of individual citizens into governmental action. As evidence of the deterioration of the environment came to light through a series of worldwide crises--on the Rhine, in the Sea of Japan, and in all major metropolitan areas--citizens reacted with demands for effective private and public measures.

At the national level, the Allies responsed by passing important new legislation and creating new organizational structures. Member nations took action to clean up existing sources of air and water pollution. Major research programs were undertaken to develop effective technology and methods to cope with new environmental problems.

It was not only on the national level, however, that effective measures took place. In the quarter century of NATO's existence, the Allies had developed habits of consultation and cooperation that paved the way for CCMS. This means of communication enabled the Allies to recognize that environmental quality was a concern common to all and deserved their joint efforts to reduce by half, any further degradation of the environment and to restore a safe and healthy environment.

This achievement should not be underestimated. The decision to talk frankly and openly with each other before national policies are decided could have only been made by countries that had developed common expectations from years of mutual problem sharing and solving. NATO's example of international trust and reliance, as much as the concrete results of the individual pilot studies, has been a major contribution to international environmental cooperation.

From its beginning, the Committee on the Challenges of Modern Society has operated differently from other international organizations. Its work is characterized by four policies that have been essential to CCMS from its outset.

First, CCMS does not work through an international staff and with a fixed budget; its work is undertaken by member countries acting as pilot countries for particular projects. Working with other interested member countries (and, over the years, with many countries not members of the North Atlantic Treaty Organization), each pilot country is responsible for developing, conducting, and disseminating the results of a pilot study. Co-pilot countries and other participants share the workload according to their interests. No member is required to participate in any study; on the contrary, each country is free to choose where to best apply its resources and expertise. Results, on the other hand, are available to all. In this way, nations whose priorities might prevent them from devoting large-scale resources to a particular problem can contribute to specific projects while benefiting from all pilot studies.

Second, CCMS has always emphasized projects that would guide policy formation and stimulate domestic and international action. While often identifying new areas for research in its "action orientation," CCMS has sought to make the results of research accessible to policy makers. At the same time, it has sought to make those policy makers more sensitive to environmental concerns.

Third, CCMS is an outward-looking and open organization. The Committee has developed complementary pilot studies on subjects that have been the concern of specialized international organizations before CCMS was formed. Examples of these areas are health, meteorology, and maritime issues. In areas where CCMS was in the vanguard of international activity--most prominently, energy conservation and alternative energy sources--its studies have helped define frameworks for bilateral and multilateral international cooperation.

Finally, CCMS has developed a follow-up procedure. Each pilot country assumes the responsibility of ensuring that its study plays the most appropirate role in stimulating national and/or international action. This furthermore indicates the Allies' support for CCMS role in national and international environmental activities.

At the completion of some studies, participants may feel there should be ongoing efforts and a formal transfer of work to a specialized international organization. Road Safety and Solar Energy Pilot Studies have followed this path. Work on other pilot studies, such as Air Pollution and Emergency Medical Services, may suggest issues for a new pilot study under CCMS sponsorship. In still other areas, the exchange of information through CCMS may demonstrate that bilateral or national efforts seems the most productive, provided that countries continue to report to the international community on their activities. Portions of the Geothermal Energy and Advanced Health Care Pilot Studies are continuing in this vain.

Formal follow-up procedures require the pilot country to report to the CCMS Fall Plenary for 2 years, following submission of the final pilot study report, on how the results and recommendations are being implemented. In practice, follow-up reporting has sometimes continued longer-notably, the four-year period following the Air Pollution Pilot Study--and sometimes, not functioned as planned.

Nevertheless, 15 have been or are now in follow-up, with more than 30 pilot studies, not all CCMS projects have lived up to initial expectations. Successful projects, on the other hand, have generated successful follow-up, stimulating both national programs and the interest of participating countries in the work of other specialized international organizations.

These four concepts--the pilot country leadership, stimulation of national and international action, open participation and results, and follow-up--are the essential components of CCMS. Together, they make it unique amoung forums for international cooperation. The flexibility demonstrated by the Allies in shaping such an organization demonstrates the versatility and ingenuity with which they have approached their other roles in NATO. They have been rewarded with the freedom to choose to work together on issues which none of them could adequately face alone. Nothing could be more appropriate than the spirit of the Alliance.

As its work program developed over the years, the relationship of The Committee on the Challenges of Modern Society with other international organizations, with national programs of the North Atlantic Treaty Organization, and with non-NATO countries also evolved. In its early years, CCMS stimulated the establishment of national environmental programs at a time when other international organizations had not yet developed environmental programs. Its encouragement of international cooperation and action helped to focus the attention of member countries on major environmental issues and problems as they developed. Through the CCMS policy of open participation, non-NATO countries were able to participate directly in its work, or, through ad hoc or other organizational arrangements with individual NATO countries, to share information and benefit from material generated by CCMS.

This relationship has continued. Since the early 1970's, not only has CCMS become more focused in its work program, it has also extended its efforts to encourage the widest possible participation by non-NATO countries. Under NATO's "silent consent" procedure, a pilot country may invite non-members to participate in a study if other Allies do not object.

Within this framework, many countries, including New Zealand, Japan, Sweden, Austria, India, the Philippines, Nicaragua, Egypt, Israel, Saudi Arabia, and Spain have been able to share in the work of CCMS. Their contributions have been extremely valuable. Notable contributions have come from

Japan and Sweden in the Road Safety Pilot Study, New Zealand in the Geothermal Energy Pilot Study, Egypt and Spain in the Advanced Health Care Pilot Study, and Israel and Saudi Arabia in the Solar Energy Pilot Study.

In working with other organizations, CCMS has been a catalyst in developing both new programs and new perspectives to existing ones. In the latter case, growing concern for environmental quality and conservation of natural resources has often meant that new issues arise within a long-standing framework of cooperation. Work by the Intergovernmental Maritime Consultative Organization (IMCO), the Organization for Economic Cooperation and Development (OECD), the World Health Organization (WHO), and the International Labor Organization (ILO) on hazardous waste, emergency medical services, occupational health and safety, and toxic substances is a new dimension to organizations originally founded for other purposes. At the same time, new organizations such as the United Nations Environmental Programme (UNEP) have been created specifically to deal with environmental issues and other challenges to contemporary society.

CCMS, both as an organization and through the Allies individually, has remained in close contact with these organizations. Development of CCMS pilot studies is always carried out only after consultation with them. Every effort is made to avoid duplication of work. CCMS strives to complement the ongoing work of other organizations. For example, faced with many more urgent global health issues, WHO has never been able to devote a major portion of its resources to emergency medical services (EMS). CCMS work in this area may today apply only to a few countries. In the future, because of EMS programs developed in the Third World, many more countries will benefit from these efforts. The same is true of efforts devoted to road safety, hazardous waste disposal, and the studies on air pollution and transportation.

Finally, from the beginning, CCMS studies have pointed the way to new modes of international cooperation within existing organizations. Programs of the International Energy Agency (IEA) on hot dry rock technology, high temperature ceramics, and climatic conditions have resulted from work initiated in CCMS. Work in the United Nations on disaster coordination and hazardous waste management predated CCMS, but has been given new dimensions by the efforts of the committee. The U.S./Canada work on inland water quality, the U.S./Mexico program on geothermal reservoir assessment, and the Greek/Italian cooperation on geothermal electricity generation have resulted from CCMS activities.

CCMS has the ability to foster such cooperation and to stimulate new activities. Faced with limited financial and technical resources, most international organizations must restrict their scope of action either topically, geographically, or both.

Also, many urgent problems are not addressed by other organizations because not all members are interested in participating. CCMS has been most successful in overcoming this kind of constraint. Since the costs of its activities are borne by the pilot and co-pilot countries, CCMS is able to conduct studies even if all members do not wish to participate. Each country determines the extent of its commitment, if any, to a particular pilot study.

In addition, CCMS is not confined to issues faced by one particular part of the world. Its one ground rule is that it does not deal with issues that mainly affect the developing countries. This recognizes the fact that United Nation countries that have dealt with the global environment, such as UNEP, WHO, FAO, and non-European regional organizations have tended to focus on the Third World.

In carrying out its mandate from the North Atlantic Council, CCMS cannot replace specialized organizations that have permanent responsibilities for dealing with problems in a given area. CCMS, however, has the special ability to bring together experts from diverse backgrounds to identify emerging issues or to tackle questions that no other organization has the resources to undertake. Through pilot studies, CCMS advances the common base of knowledge and broadens the channels of cooperation through which all national and international programs must operate.

Assessing the results of the pilot study on solar energy, the Federal Republic of Germany commented that it "had been given the benefit of experience and had thus gained one year in its research program." Given the number and complexity of problems faced by countries and international organizations around the globe, the contribution of months, or even days, to ongoing programs may make a crucial difference. Complementing and supporting the work of other international organizations is one of the most important ways in which CCMS fulfils it obligation under the North Atlantic Treaty: to promote peace, stability, and well-being throughout the Alliance and around the world.

The Committee on the challenges of Modern Society (CCMS) has undertaken more than 30 pilot studies. Their subject matter ranges over all aspects of human existence. The choice of topics is made by member countries and reflects current national priorities. There has been no master plan or overall organization. Instead, certain patterns for selecting study topics have emerged.

Air pollution, from the very start, has occupied an important place. Over the years, the broad concept of air pollution was defined into several specific studies. The studies grew and branched off into new directions. These have ranged from information exchanges to the development of new technologies and measurement techniques.

Similarly, over the last decade, there have been several studies centered on water pollution. These began with the Inland Water Pollution Pilot Study, concerning man's discharges into streams and lakes. Advanced processes for treatment of waste water were demonstrated. CCMS also took on issues of marine water pollution, including the effect of oil spills on coastal water. An even wider perspective is being opened in estuarine management, which encompasses all aspects of man's impact in the regions where fresh water meets the sea.

Although initially presented as a single study, the Advanced Health Care Pilot Study has consisted of several projects which have been diverse in subject matter and means of accomplishment. The study included emergency medical services, begun originally as a road safety project and has now grown into a pilot study.

Transportation, with an emphasis on safety, has also been a primary object of attention. As initial projects were completed, new ones examining other aspects began. Efficient planning of mass transportation and providing economical, reliable transportation to the greatest number of people became a new thrust of these studies.

Another group of studies has focused on waste management. CCMS began its work in the area of hazardous waste disposal. The success of the first Disposal of Hazardous Wastes Pilot Study led to continued cooperation in a second study. The Committee is now looking at the potential of plastic waste recovery. A proposal to investigate the combined disposal of solid waste and sewage sludge is also under consideration.

Pilot studies on the energy focused international attention on solar and geothermal energy development. Energy studies stressed the development of integrated systems of energy conservation, use of alternate sources, and maintenance of environmental quality.

CCMS has also conducted pilot studies on other ways man interfaces with his environment. Studies on disaster assistance and seismology deal with the problems posed by natural crises. A new study on conservation of monuments applies the techniques of pollution monitoring and control to preserving our cultural heritage.

CCMS follows no set procedure when developing a pilot study. The participants can work together in three main ways. The simplest way is for each country to carry on activities in its own fashion, and, at some point, communicate the results to other members. This approach is often taken in the case of projects of a major pilot study, in which a single country carries out a specific project. The Urban Transportation Pilot Study is an example of this type.

A second way is for the participants to work individually, but according to a common framework. For example, as part of the Solar Energy Pilot Study, a CCMS format was developed for reporting the performance of solar heating and cooling systems. This enabled the project members to then meet and compare the merits of different systems.

Finally, two or more participants may carry out the work jointly. For example the United States and Mexico worked together to study the Imperial Valley geothermal field. The involvement of Mexico also illustrates the fact that non-NATO countries may actively participate in CCMS.

Most pilot studies eventually turn out to be in combination of these three approaches. The method chosen depends upon the particular circumstances of each pilot study. This underscores the advantages of the flexible CCMS mode of operation.

There is also a wide diversity in the results of pilot studies. The outcomes can take many forms, from international conventions to state-of-the-art reports, to computer data banks, to the construction of equipment. Aside from tangible products, of equal importance are the intangible results such as the establishment of networks of experts, the changes in national policies, or the creation or reorientation of institutions.

(Adapted from "CCMS: The First Decade." U.S. E.P.A., 1979)

A list of current, completed and follow-up phase studies follows.

## NATO COMMITTEE ON THE CHALLENGES OF MODERN SOCIETY (CCMS)

## WORK PROGRAM

A. PILOT STUDIES - CURRENT

1. REMOTE SENSING FOR CONTROL OF MARINE POLLUTION

   Pilot Country: France
   Copilots: Greece, Turkey, US

   a. Detection of Oil Spills and Hazardous Substances at Sea - Working Group I (US)

   b. Study of Coastal Pollution Movements - Working Group II (France)

   c. Deferred for time being - Study of Effect of Air Pollution on the Sea

2. DRINKING WATER

   Pilot Country: United States
   Copilots: UK, FRG

   a. Analytical Chemistry and Data Handling (UK)

   b. Advanced Treatment Technology (FRG)

   c. Microbiologicals (US, France)

   d. Health Effects (US)

   e. Reuse of Water Resources (UK)

   f. Ground Water Considerations (FRG)

3. SEISMOLOGY AND EARTHQUAKE LOSS REDUCTION

   Pilot Country: Italy
   Copilots: France, UK, US

   a. Seismic Risk

      (1) Estimation of Seismic Risk (UK)

      (2) Seismic Risk in Heavily Populated Areas with Emphasis on Characterization of Strong Ground Motion (Italy)

      (3) Studies of Induced Seismicity (US)

   b. Earthquake Prediction (France, Italy, US)

   c. Earthquake Loss Reduction (US)

4. HYDROLOGICAL FORECASTING IN THE MANAGEMENT OF WATER RESOURCES

Pilot Country: France
Copilots:

a. Phase I - Information Exchange

b. Phase II - Dependent on Assessment of Initial Exchange

5. ROLE OF TRANSPORTATION IN URBAN REVITALIZATION

Pilot Country: United States
Copilots:

a. Selection of Case Studies and Limited Information Exchange

b. Analysis of Case Histories

6. MAN'S IMPACT ON THE STRATOSPHERE

Pilot Country: Canada
Copilots: US

a. Tunable Laser Diode Spectrometer (TLDS) Development and Testing

   (1) Laboratory Study of TLDS System Operation under Stratospheric Conditions to Determine Payload Design Parameters

   (2) Payload Design and Fabrication

   (3) Payload Integration in Flight Vehicle

   (4) Flight Test of TLDS System

   (5) Analysis of Results

   (6) Completion of Final Report (1982)

b. Definition Phase

   Canvassing of International and National Organizations to Assemble Basic Inventory Material

c. Assessment of Results and Formulation of Recommendations

7. CONSERVATION/RESTORATION OF MONUMENTS

Pilot Country: Greece
Copilots: FRG, France, US

a. Documentation (France, US)

b. Environmental Factors (FRG, US)

c. Treatment Testing Methods (The Netherlands)

8. AIR POLLUTION CONTROL STRATEGIES AND IMPACT MODELLING

Pilot Country: Federal Republic of Germany
Copilots: The Netherlands, US

a. Heavy Metals Emissions (FRG) - Panel 1

b. Air Quality Prediction (The Netherlands) - Panel 2

c. Environmental Impact (US) - Panel 3

d. Ad Hoc Group on the Total Air Pollution Cycle

9. UTILIZATION AND DISPOSAL OF MUNICIPAL SEWAGE SLUDGE

Pilot Country: United States
Copilots:

a. Legislation, Environmental Regulations and Administrative Aspects (FRG)

b. Disposal Methods (Land and Ocean)

c. Sewage Sludge Utilization and Processing into Secondary Materials (France)

d. Incineration and Energy Conversion

10. INTEGRATED PEST MANAGEMENT (IPM)

Pilot Country: United States
Copilots: Turkey

a. Initial Information Exchange

b. Research on IPM Procedures for Following Specific Crop Areas:

(1) Cereal
(2) Citrus
(3) Cotton

c. Under Consideration: IPM Procedures for vegetables, potatoes, glasshouse crops, tobacco, livestock, and urban environs

## 11. REGULATIONS CONCERNING APPLICATION AND PRODUCTION OF PHEROMONES

**Pilot Country:** The Netherlands
**Copilots:**

## 12. CONTAMINATED LAND

**Pilot Country:** United Kingdom
**Copilots:**

## 13. LIGHTER-THAN-AIR AIRCRAFT

**Pilot Country:** France
**Copilots:**

## 14. PROTECTION OF MEDIAEVAL GLASS WINDOWS

**Pilot Country:** Federal Republic of Germany
**Copilots:**

a. Glass samples are made available, characterization of the corrosion layer

b. Selection of suitable coating material and coating

c. Open-air exposure of the coated samples

d. Assessment of coated sample behaviour

## B. PILOT STUDIES - FOLLOW-UP PHASE

### 1. ADVANCED WASTE WATER TREATMENT

Pilot Country: United Kingdom
Copilots: Canada, Italy, France, FRG, US

### 2. AIR POLLUTION ASSESSMENT METHODOLOGY AND MODELLING

Pilot Country: Federal Republic of Germany
Copilots: Belgium, US

### 3. FLUE GAS DESULFURIZATION

Pilot Country: United States
Copilots: FRG, UK

### 4. IMPROVEMENT OF EMERGENCY MEDICAL SERVICES - CCMS/WHO/PAHO

Pilot Country: United States
Copilots:

### 5. RURAL PUBLIC TRANSPORTATION (or RURAL PASSENGER TRANSPORTATION)

Pilot Country: United States
Copilots:

## C. PILOT STUDIES - COMPLETED

1. ENVIRONMENTAL AND REGIONAL PLANNING

   Pilot Country: France
   Copilot: UK

2. DISASTER ASSISTANCE

   Pilot Country: United States
   Copilots: Italy, Turkey

3. ROAD SAFETY

   Pilot Country: United States

4. INLAND WATER POLLUTION

   Pilot Country: Canada
   Copilots: Belgium, France, US

5. ADVANCED HEALTH CARE

   Pilot Country: United States
   Copilots: Canada, FRG, UK, Italy, Portugal

6. URBAN TRANSPORTATION

   Pilot Country: United States
   Copilots: Belgium, France, FRG, UK

7. DISPOSAL OF HAZARDOUS WASTES - PHASE I

   Pilot Country: Federal Republic of Germany
   Copilots: Belgium, France, UK, US

8. AIR POLLUTION

   Pilot Country: United States
   Copilots: FRG, Turkey

9. COASTAL WATER POLLUTION

   Pilot Country: Belgium
   Copilots: Canada, France, Portugal

10. NUTRITION AND HEALTH

    Pilot Country: Canada

11. GEOTHERMAL ENERGY

Pilot Country: United States
Copilot: Italy

12. RATIONAL USE OF ENERGY

Pilot Country: United States

13. AUTOMOTIVE PROPULSION SYSTEMS (APS)

Pilot Country: United States

14. PLASTIC WASTES RECYCLING

Pilot Country: United States

15. DISPOSAL OF HAZARDOUS WASTES - PHASE II

Pilot Country: Federal Republic of Germany
Copilots: Belgium, Canada, France, US

16. SOLAR ENERGY IN HEATING AND COOLING SYSTEMS OF BUILDINGS - PASSIVE SOLAR APPLICATIONS GROUP

Pilot Country: United States
Copilots: France, Denmark

17. MANAGEMENT OF ESTUARINE SYSTEMS

Pilot Country: United States

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